A LEARNING TOOL FOR MOLE CONCEPT

INTERACTION DESIGN PROJECT III

IN III - 90

BY

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Approval Sheet

The project titled A Learning tool for Mole Concept by Labeeba K, is approved for partial fulfillment of the requirement for the degree of 'Master of Design' in Interaction Design.

Guide

Chairperson

Internal Examiner

External Examiner

Date 6th JUNE 2016

Declaration

I declare that this written document represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not misinterpreted or fabricated or falsified any idea/data/fact/source in my submission.

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Abstract

Chemistry is first introduced to the students in 8th standard in Indian schools. It is different from the other subjects due to its abstract nature and students inability to visualize the three levels- macroscopic, submicroscopic and symbolic levels. It is still taught through rote learning with little importance on understanding student misconceptions, the micro-macro connection and its relevance in the everyday world. Mole concept is one such basic topic that is misunderstood by teachers and students alike.

From the numerous research available and the user study, the hardspots of learning mole are identified as the lack of knowledge of future use, lack of important prerequisite relative atomic mass, misconceptions, lack of link between mole , atomic model and other parameters like mass-volume, language ambiguity and lack of imagining small size of atoms and magnitude of Avogadro number.

Using the conclusion that a combination of breaking misconceptions and learning prerequisites is the effective way to deal with mole, two concepts were explored through prototypes. It was also concluded that the limelight should be on students exploration rather than on teaching.

The first concept, 'Mole scope' mainly focussed on the lack of connection between atomic and macro chemistry and lack of visualization of mole. Mole scope is like a microscope from real world into the mole world and back, in different levels.The molescope video was tested with children for its effectiveness in learning mole, but it didnot yield the required results.

The second concept, 'Molegyan' focused on breaking the misconceptions on the subject through developmental activities for the students. It is a stand alone self -learn interactive tool for the students of class 9th and 10th. The tool takes the students through 4 levels of activity, each on the identified learning outcome. The first two levels are on the prerequisites of mass and relative atomic mass. The major focus is on level-3 and 4 which introduces mole and is use in stoichiometry. The tool gives a feedback report and suggestions at the end to the students. The feedback given by the tool to the students actions are the major element that is used to help children learn.

The prototype created using the above concepts was tested with students of KV School and GVHSS Koduvally. It is found that a mixture of video learning and activities in the order of correct prerequisites, like used in molegyan is good for self learning mole concept. Mole gyan has an edge over others due to the fact that the nested concept is covered entirely at one place through interesting activities and the students need not search for multiple sources.

Introduction

“Education is an admirable thing, but it is well to remember from time to time that nothing that is worth learning can be taught.”
— Oscar Wilde

Chemistry is one of the most important branches of science; it enables learners to understand the various chemical and physical changes happening around them. As chemistry topics are generally related to or based on the structure of matter both atomic and macro properties, chemistry proves a difficult subject for many students. Chemistry curriculum usually has many abstract concepts, which are central to further learning in both chemistry and other sciences (Taber, 2002).
While doing my research seminar which was on online collaboration among teachers, I also interacted with teachers of a government school in Kerala. Difficulty to teach certain science concepts in the limited time available was the major point of discussion. Lack of motivation and attention in class and lack of efficient teachers who can manage students were major problems. Hence, I had the interest to work on developing a tool which will make learning fun and hence reducing the stress on teachers.

My motivation mainly stemmed from my mother who was a chemistry teacher in the same school. I decided to take up chemistry, as it was one of my favorite subjects and also, it is based on various abstract concepts that were difficult to teach.

The project is not entirely about one topic or subject, but an exploration on how children learn and develop their skills of assimilating further knowledge. As child progresses through different levels of education, the concepts they learn help them to add to their existing knowledge and broaden their world view. But how they learn has a much higher significance on helping the students to effectively link the new information(schemas) so that they do not forget the basic technique of linking thoughts and it is easier for them to link other complex concepts to existing schemas. This higher purpose is often lost in todays education where all concepts are taught through rote learning.

Why mole concept ?

In a study at government higher secondary school-koduvally, chemistry teachers were asked to rate difficulty of topics they teach[1]. Eight out of ten answered mole concept to be a tough topic. 4 others also suggested organic chemistry. According to students, organic chemistry and mole concept were 2 tough topics to learn. There were exceptional cases who found organic chemistry very easy.

Through research it was found that mole concept is a acknowledged as difficult topic to learn universally. During my school years, I also had misunderstood the concept at various levels leading to difficulty in the laboratory work. Other abstract concepts like atoms, elements, atomic model have been researched and various tools are available, But for mole concept, videos and lab experiments are the only innovative tools available.

Initial Objectives

The initial product objectives were -
1. The product should help children learn and practise the concept without teachers aid in small groups.
2.The tool should keep students engaged without boredom.
3.The tool should help students solve problems related to mole concept.
3. The overall tool should be scalable to other concepts, if possible.

Target User

The primary users are 8-12th standard students of Indian CBSE, ICSE or state syllabus schools. It can also be useful for students at tuition centres.

The secondary users are the chemistry teachers who are indirectly helped as students use the product. The teachers introduce the product to the students at the first place.

Context of Usage

As the current curriculum and way of teaching cannot be altered totally, the tool will serve as a supplementary aid to the content. The teachers can suggest the tool as an additional aid to practice and self learn. Or this can be purely a self learning application downloadable from the internet.

1. The study was done among 10 science teachers in GHSS Koduvally. They were asked which was the most difficult topics in their syllabus, why and how this issue can be sorted. Most of the teachers had mole concept as one of the topics listed.

Design process

Content Analysis

Once mole concept was decided as the topic of interest, the content provided in NCERT and Kerala SCERT syllabus were studied. Focus was given to the approach of instruction, difficulty level and content range. A study was done to identify why the concept is considered abstract through various research papers written about teaching mole to highschool students in various countries. Other forms of learning, like Ted ed video 'How big is mole?' and Khan academy video was analyzed. The entire content was divided into principles, facts, concepts (based on Component Display Theory[2]) and recorded how each was taught by the syllabus. These studies resulted in coming up with a script for teaching mole and compiling initial learning objectives.

User study

User study was conducted in govt.. higher secondary school, Koduvally and KV School, Powai. This included teaching concept to children, interviews with teachers, discussion with educators and group discussion with children.

Secondary research

Secondary study mainly focused on various learning theories, famous learning experiments and ways used to teach abstract concepts as one part and the other part, a research on learning products for science and how they dealt with mole.

Design brief

Both the previous studies helped in coming up with the brief, final learning objectives and what the optimum characteristics of the product should be. Visualization of mole and the feel of Avogadro number through real and everyday objects remained as the major objective.

Ideations

Ideas were mainly brainstormed for visualizing mole by stories and exploring elements and compounds in micro and macro world. Out of the 5 ideas, mole visualizer was developed.

Design exploration 1

Mole visualizer was developed as an movie clip called mole scope. A scenario to show how big a mole is actually was also made by finding the mole of sand grains. Both were tested with students and teachers. From evaluation and jury feedback it was understood there are other hard-spots which if solved will solve the major issue and more emphasis should be given to misconceptions created or might be created in childs mind.

Re - study and research

A restudy was conducted on identifying misconceptions in mole and the topics in which mole is nested. From this further learning objectives were found and ideated.

Design exploration 2

Scenarios were plotted for each of the hard-spots initially. But finding they are very linear and might be boring for students, developmental activities were formulated that can be used by students.

Evaluation

Heuristic evaluation is planned on the final product. A usability and learning test will be conducted on three of the levels against learning objectives.

2. Merrils Component Display Theory (CDT) classifies learning along two dimensions: content (facts, concepts, procedures, and principles) and performance (remembering, using, generalities). This format has been used for content analysis in the next section. (instructionaldesign,2016)

Content Analysis

In CBSE syllabus, mole is taught in the 9th standard while SCERT Kerala teaches it in 10th standard. . The major laboratory applications of mole concept happens in 11^{th} and 12^{th} standards and its associated topics like stoichiometry, molarity and molality.

Mole concept is a nested concept which has various underlying principles and concepts inside it. It is necessary to analyze how deep students understanding in these prerequisites are in order to start with mole.

The study progressed and resulted in the following:

1. Total content in the form of a teachers script with required metaphors and examples

2. Content was analyzed based on Merrils Component Display theory

The Content

I explain the content of mole concept through a script made from insights of various syllabi. The script was made based on the importance given to various principles in the content analysis, and the areas I needed to emphasize to help children learn the concept.

This was used in the classroom trials as my way of explaining mole concept.

Introduction

Today, lets learn about mole.

Well, a mole is a concept that we use in chemistry to count molecules, atoms, or just anything extremely small.

Why is there so much interest on atoms and counting them ? Because all the matter in universe is made up of atoms and the reaction between these atoms create everything that exists around us like a pencil or pen in your hand, the book, the air around you, or you yourself. Have you ever wondered how many atoms are there in our galaxy, or in the water you drink or inside you ?

Future use

But chemists wanted to find an answer to this. They wanted to know how to count or quantify atoms to use for making chemicals and experiments. Hence, a unit mole was devised to count small particles like atoms.

Atoms are small

But, atoms are extremely small. How is it even possible to count them?

Consider this situation. Imagine that 2 of you went to a kirana shop for a job. The shop owner gave a task. “This sack is full of green gram. All grains have equal mass. I want 10,000 grains as fast as possible and whoever finishes first will be hired” What will you do? Will you sit and start counting 10,000 grains with your hand? Not really. You'll get a weighing machine. Weigh 100 grains of green gram. And lets say it weighs 5g.

So, you know that a packet of 100 grains of green gram will always weigh 5gms as each grain is of same mass. Now to get 10,000 grains you just have to weigh out 100 packets of 5gm each. Or take 500gms.

No. of particles and mass

Hence we can conclude that in case of particles of same mass, a fixed mass will always contain same number of particles. i.e. from number of particles total mass can be found out and from total mass , number of particles can be found out .

This is the case of atoms also. Atoms and molecules of an element are particles having fixed masses. Hence, their number in a known mass of an element can be estimated using this method.

But what should the standard capacity be?

1 dozen of atoms = 12 atoms =--- grams. But this weight is too small to weigh

1 gross of atoms = 144 atoms. .Even this mass is very small. Hence a larger unit ‘ mole ‘ was coined. How much should 1 mole weigh or count ? how did chemists find that?

‘1 mole’ = ? = ?gram

What should this fixed mass be = --------

Is it possible to find a relation between this mass and RAM ?

In order to make the calculations easier for all elements scientists, equated it with relative atomic mass or RAM.

Relative atomic mass

Now , what is RAM ?

Atoms of each element have different masses . As atoms are extremely small, this mass is also extremely small

Mass of hydrogen = 1.67×10^{-24} g

This is very very small. It is difficult to work with such small numbers, Scientists decided to measure them using relative masses i.e., Consider weight of hydrogen atom as 1 , then carbon atom is 12 times heavier than hydrogen. Hence

RAM of carbon is 12

RAM of Hydrogen = 1

RAM of Oxygen = 16

This is Relative atomic mass.

RAM and Molar mass

Now, let us take Hydrogen and Carbon atom and compare their weights

	H	C
Mass of 1 atom	1	12
Mass of 2 atom	1	12

If I take 1 atom of hydrogen and carbon ,the proportion of weight will be 1:12

If I take 2 atoms of hydrogen and carbon, the proportion of weight will still be 1:12

So if I take 1 gram of Hydrogen atoms and 12 gram of carbon atoms, the no. of atoms will still be the same and that was experimentally found as 6.023×10^{23} atoms.

Mole and Avogadro number

This amount of each element containing 6.023×10^{23} atoms and having weight equivalent to its relative atomic mass(RAM) is called a mole of that element atom. And the gram equivalent of RAM is called gram atomic mass.

1 mole of oxygen atoms contains 16 g of Oxygen and Na number of oxygen atoms. 1 mole of water contains 18 g of water and contains na number of H_2O molecules.

How big is mole?

Let us take the example of water molecules. If we pour 18g of water into a glass, which is 18ml, and which is like 3 and half teaspoons of water, You'll have 602 sextillion molecules of water. Since a person called Amedeo Avogadro was the first one to come up with the idea of mole with gas particles, scientists named the number 6.023×10^{23} after him simply known as Avogadros number.

Moles are hard for you to understand because its hard to picturize the size of mole.

Remember the 18ml of water ,that is a mole of water. But how much is that. exactly what is 6.023 x 10^{23} look like. Lets see,Replace the water particles for vadapavs. If you had a mole of vadapavs, then it will cover the entire earth to a depth of 8 km. If you had a mole of apple, you can create another moon of apples.

To conclude, atoms are extremely small, we need to count atoms and measure them in grams and hence a unit mole was introduced which is the amount of element that contain Avogadro number of atoms and it has a mass equivalent to the elements' RAM. And mole is indeed a huge number.

Fig.3: Content split up according to merrils Component Display Theory

MOLE CONCEPT - CONTENT ANALYSIS

	TOPIC	CONTENT	FUNCTION
PRINCIPLE	Chemical reactions and proportionate number of reactants	Reactions happen when atoms and molecules are put in certain known proportions. If not the reaction will be half complete with lot of unwanted residue.	Why is mole concept taught?
FACT	Atoms and difficulty in measuring and counting	Atoms are unimaginably small. It is difficult to count atoms and measure atoms due to its small size and mass.	Why mole?
PRINCIPLE	Number and mass	In case of particles of same mass, a fixed mass will always contain the same number of particles. So, from mass one can find the number of particles and from number one can find mass	
PRINCIPLE	Atoms and atomic masses,RAM	Atoms of different elements are of different masses . The masses are measured relatively due to difficulty to measure i.e, masses of elements are proportionate in nature	To teach relative atomic mass - amu RAM hydrogen - 1, oxygen - 16, carbon-12
CONCEPT	Mole concept 1	So, when we take these elements in grams in the same proportion as their relative atomic mass, the number of atoms will be same. So, A chemist avogadro decided to measure this number for carbon element and found 6.023x 10 23 atoms in 12 g of carbon	Macro and micro chemistry relationship1:12 amu and 1:12 g ....Why Na ?
FACT	Gram atomic mass	the gram value of different elements which are numerically equal to their relative atomic masses	h- 1g, o- 16g
FACT	Avogadros number	Introducing avogadros number	why na = 6.023x10 raised to 23
CONCEPT	Mole concept	Mole is amount of any substance which contain na number of particles of that substance. 1 mole of carbon contains avogadro number of carbon atoms and it weighs 12g. 1 mole of h2o contains avogadro number of h20 molecules and proportionate to carbon it weighs 18g(carbon atom : hydrogen atom = 12:1 and carbon atom :oxygen atom = 12 : 16)	
FACT	Molecular mass and gram molecular mass		mole for diatomic and polyatomic molecules, hydrogen molecule - 2g, h2o - 18g

Analysis : NCERT syllabus

Presentation

NCERT had a very textual way of introduction and presentation even in the introduction of chemistry for the first time to students. It is up to the teachers how to make the topic interesting.

There were large chunks of data with text and problems versus a small (Fig.) in the NCERT textbook. Lack of context and localization to the geographic location is not used to relate students to real world scenario. The book jumps directly to the definition, without summarizing and introducing the connection with prerequisites.

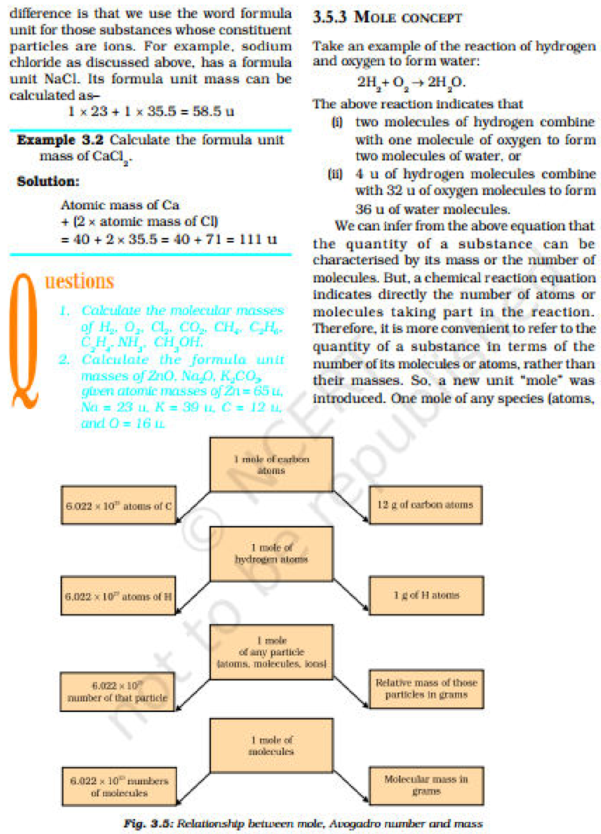
Structure

NCERT had a very rigid structure to its contents.

Introduction · Content · Solved problems·

Extra notes · Questions · Evaluation

This helped all teachers to follow same approach of teaching. Various questions arose from the teachers such as Why does the number of activities reduce in science while social sciences had a number of activities to choose from. It is the burden of the teachers to find credible activities and their reliability is very less.



difference is that we use the word formula unit for those substances whose constituent particles are ions. For example, sodium chloride as discussed above, has a formula unit NaCl. Its formula unit mass can be calculated as–

$$1 \times 23 + 1 \times 35.5 = 58.5 \text{ u}$$

Example 3.2 Calculate the formula unit mass of $CaCl_2$.

Solution:

Atomic mass of Ca
+ (2 × atomic mass of Cl)
$= 40 + 2 \times 35.5 = 40 + 71 = 111$ u

Questions

1. *Calculate the molecular masses of H_2, O_2, Cl_2, CO_2, CH_4, C_2H_6, C_2H_4, NH_3, CH_3OH.*
2. *Calculate the formula unit masses of ZnO, Na_2O, K_2CO_3, given atomic masses of Zn = 65 u, Na = 23 u, K = 39 u, C = 12 u, and O = 16 u.*

3.5.3 Mole concept

Take an example of the reaction of hydrogen and oxygen to form water:

$$2H_2 + O_2 \rightarrow 2H_2O.$$

The above reaction indicates that

(i) two molecules of hydrogen combine with one molecule of oxygen to form two molecules of water, or

(ii) 4 u of hydrogen molecules combine with 32 u of oxygen molecules to form 36 u of water molecules.

We can infer from the above equation that the quantity of a substance can be characterised by its mass or the number of molecules. But, a chemical reaction equation indicates directly the number of atoms or molecules taking part in the reaction. Therefore, it is more convenient to refer to the quantity of a substance in terms of the number of its molecules or atoms, rather than their masses. So, a new unit "mole" was introduced. One mole of any species (atoms,

Fig. 3.5: Relationship between mole, Avogadro number and mass

Fig.4.NCERT chapter presentation
Source : NCERT Standard 9th science textbook

Analysis : SCERT syllabus

SCERT Kerala divided the chapter mole concept into 3 modules. 1st module dealt on the reason behind making the term 'mole' and its application. The book had larger content and importance given to the topic. Most of the content was stories and examples.

The SCERT educators believe that the word 'mole ' is confusing and it is the reason for the difficulty. Hence it is introduced in the second module.

Issues identified are that there was too much of content for high school students; topics related to concentration can be dealt in higher secondary class. Learning is based on principles behind mole rather than rote learning facts and problems as in NCERT.

Each principle is started with analyzing a story or scenario involving the children and deriving conclusion and then coming to the main content. Only after this problems are studied.

Localized metaphors like counting fruits in a kirana shop and counting coins in a bank are used in teaching relation between number and mass. Both textbooks and teachers are in unison about problem solving based on pattern formation and tables.

Fix a lighted candle over a glass plate and cover it with a glass tumbler. Why is the flame put out?

Candle exhausted/Oxygen exhausted

(✓ the correct answer)

Fig.5 : Introduction for a principle with an experiment or scenario in SCERT textbook

Source : SCERT Kerala 10th std science textbook

Existing research

I looked in to the research that has gone into mole concept that validates that it is indeed a difficult abstract concept and why is it so.

A study finds that students' success in stoichiometry problem solving depends mainly on their understanding of the concept of mole and conceptual understanding of the problems. The study conducted with urban school children of Malaysia however concludes mathematical ability is not a significant factor in determining students' success in solving the problems. (Hafsah ,2014)

Also, students have difficulties in 'making sense' of the chemical reaction(problem representation) itself. (Tsoi Mun Fie,1998)

Efe M. Omwirhiren in his phD thesis on learning mole concept by students in Nigeria suggests that the students' error in solving problems in mole concept was due to their weaknesses in stoichiometry and basic arithmetical operations. (Efe M. Omwirhiren,2007).

The findings of a similar study in japan indicates that students may fail to construct meaningful understandings of the mole concept for the following reasons:(1) inconsistency between the instructional approaches of the textbook and teacher; 2) confusing mole concept vocabulary;(3) students' math anxiety and proportional reasoning ability;(4) learners' cognitive levels; and (5) lack of practice in problem solving. The learning logs of this study are very interesting with the activities done in the class over a period of time. (Larson, Jane, 1997)

The researches can be concluded as following-

· Difficulty in understanding the concepts definition without the history of changes

· Difficulty in relating to micro - macro chemistry

· Confusion of students and teachers over mole and mass, number and amount of substance

· Problems of understanding the relation between "amount of substance" (the quantity) and "mole" (the unit)

· Concept's level of abstraction vs. cognitive developmental stage of the students

Take away from content analysis

Any material that help to learn mole should relate between micro and macro chemistry.

It should explain molar interpretation in chemical equations.

Usage of scenarios or stories to explain principles is a good learning method for the target user.

Usage of localized metaphors and analogies like mole shop or mole bank, atoms as fruits etc. will help in relating to the students real world.

The product should prompt students to do experiments with chemical substances.

Secondary Research - Literature review

Learning vs Teaching

Learning is actually an interaction between the existing knowledge and new knowledge.

Today's education system is seriously flawed as it focuses on teaching rather than learning. “Why should children or adults be asked to do something computers and related equipment can do much better than they can?”(Russel L.Ackoff, 2008)

It is a much acknowledged fact that when those who have taught others are asked who learns most in class, everyone says it is the teacher. It is apparent to those who have taught that teaching is a better way to learn than being taught. Teaching enables the teacher to discover what one thinks about the subject being taught. Currently the schools work upside down. We should let the students to teach and the faculty to learn from them.(upenn.edu, 2016)

There are many different ways of learning; teaching is only one of them. We learn a great deal on our own, in independent study or play. We learn a great deal interacting with others informally sharing what we are learning with others and vice versa. .

We learn a great deal by doing, through trial and error. Long before there were schools as we know them, there was apprenticeship. (Russell L .Ackoff, 2008)

Garners theory of multiple intelligence also suggests that all students do not come with the same intelligences, they can learn effectively if they express their thoughts in the way that they are good at , may be through music, dance , art etc. (tecweb. org, 2016)

This is why one room rural schools(negroponte, 1998) is works as opposite to teacher explaining to students, here students explain to each other and this continues making them learn. Expressing what they have learned in any form comfortable should be a part of learning.

The issue came when mass education was introduced and polishing the children to adults for a particular skill and job started happening. Hence, mass education with same objectives for all students should not be the ultimate goal.

Fig.6 : EJ and spot comic showing the difference between teaching and learning
Source : Google Images

Misconceptions

Jim minstrell of facet innovations have worked on misconceptions in science and outlined how to help teachers in breaking misconceptions for various science topics. He developed a diagnostic tool (diagnoser, 2003) which details the topic for both teachers and students and gives students quizzes from real life to solve. The issue with the diagnoser is that students who are motivated already can work though the quiz. If the same is used with visualization, it might be helpful. (Facet innovations, 2016)

This project implemented a facets-of-thinking perspective to design tools and practices to improve high school chemistry teachers' formative assessment practices. Goals are to identify and develop clusters of facets related to key chemistry concepts; develop assessment items; enhance the assessment system for administering items, reporting results, and providing teacher resource materials; develop teacher professional development and resource materials; and examine whether student learning in chemistry improves in classes that incorporate a facet-based assessment system. (diagnoser, 2003)

Jim minstrells diagnoser did a detailed study on misconceptions for many topics in highschool science and gave the following resources.(Facet innovations, 2016)

Learning Goals (Aligned with National Science Education Standards and Benchmarks for Scientific Literacy)

Facet Cluster (i.e., a grouping of productive and unproductive facets of student ideas, with as much structure as possible. Includes the explicit learning goals in addition to various reasoning, conceptual, and procedural difficulties)

Elicitation Question (i.e., pencil-and-paper questions that can be delivered to students to elicit their prior ideas about a subject)

Developmental Lesson(i.e., a conceptual story for instruction of a very small set of concepts in a particular topical area)

Diagnoser Question Sets (i.e., web-delivered sets of multiple-choice and open-ended research-based formative assessment probes. Students receive feedback on their thinking as they work through their assignment. Teachers can access reports on students' thinking related to the assigned content.)

Prescriptive Activities (i.e., topic-dependent suggestions for instructional interventions to help individual students or small groups, whose answers to the Diagnoser Question sets are consistent with specific problematic facets).

(Facet innovations, 2016)

Language issues and ambiguity

One major reason identified as leading to whole misconception is the vocabulary mole itself. 1 mole can be of any particle and hence has many meanings. It has been researched whether language is a contributing factor for the existing dilemma with mole. (B Pekdag,2013)

There is a diversity of language used to establish the concept of amount of substance and this causes problems for many students. For example, mole is similar to molecular, molarity and molecule . Additionally the name of the quantity "amount of substance" is used to mean mass or volume in everyday language .

A recent study analyzed the coverage of the 'amount of substance concept' in 15 different textbooks, uncovering a number of flaws along the way. A key point, which has been stressed by IUPAC, is that the 'elementary entities' (e.g. atoms, molecules, ions) must be specified when the term 'mole' is used. This point is one which is often missed, even in textbooks and learning.(B Pekdag,2013)

Some of the errors discussed are subtle, an example which is 'How many moles are in 45.6 g NH_3?', which was corrected to 'What is the amount of substance in 45.6 g of the compound NH3?'. Some mistakes stand out as being clearly incorrect, for example 'The molar mass of the Na atom is 22.99 g' which was corrected to 'The molar mass of the element Na(s) is 22.99 g mol-1'. By combining macroscopic and microscopic concepts, this error may confuse students, or perhaps even lead to misconceptions. (David Read, 2013).

Existing learning methods

While studying various platforms, I am mostly looking at how they have tried to teach or helps student learn mole concept and similar topics, not only the various additional features.

1. cK 12 online MOOC

(ck12, 2016)

This is a typical example of a MOOC for mole concept. This had set objectives and this is aimed at motivated students who follow a systematic way of learning. The MOOC is embedded with Ted Ed, khan academy videos. Students can learn at their own pace.

No particular innovative feature was employed in developing the concept of mole.

2. Texas gateway for online resources

(texasgateway, 2016)

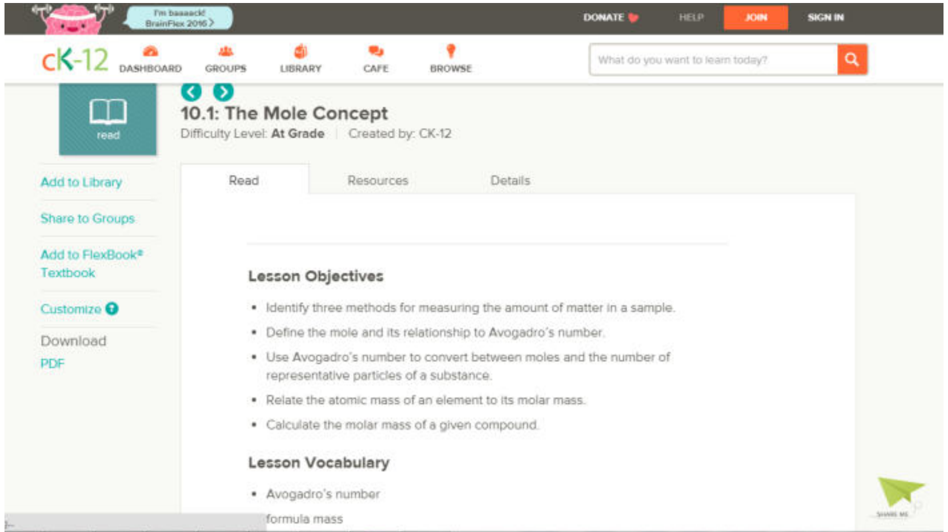
This is the best well structured MOOC I have seen about mole concept, But it is also very textual in nature. Only students who are innately motivated will be interested in reading it. The main features

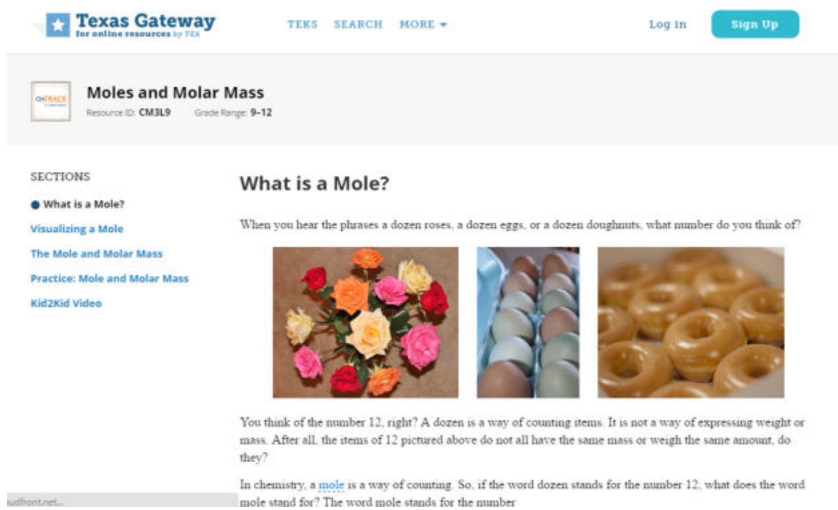
Fig. 7: CK12 online MOOC interface

Source : http://www.ck12.org/book/CK-12-Chemistry-Intermediate/section/10.1/

Fig.8: Texas gateway introduction

Source : http://www.texasgateway.org/resource/moles-and-molar-mass





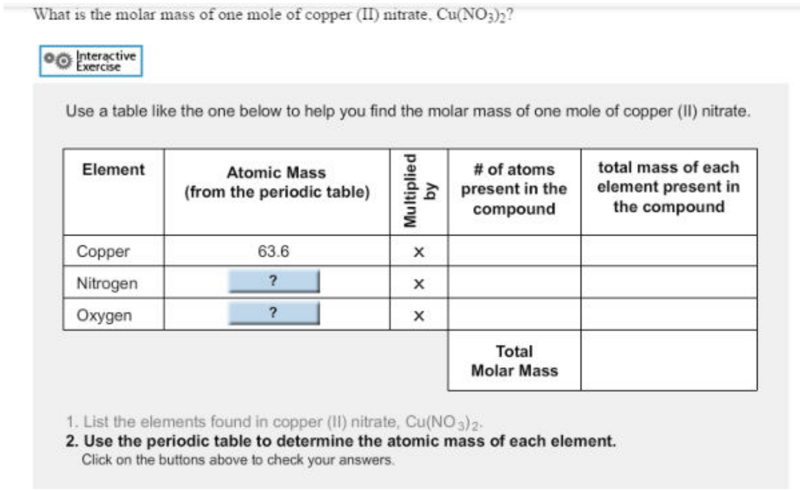
are the numerous examples in very realistic and experimental manner and the interactive exercises.

This provided interactive exercises for the students and activity oriented steps to follow. But, even this do not reduce the disengagement in students

3.Zaption gallery

Zaption is an online site that helps teachers find, alter, and use their ready to use educational content. The good feature is that the teacher can add his own/external videos as require and tasks and interactive quizzes can be added. This reduces the teachers load and makes their work easy.

There were 2 teaching material for mole concept. One from Ted Ed video and other made by a tutor. In zaption, the teacher used 3 frames, one to show him talking, one to show his hands drawing on the table, and one to display the texts and quizzes in between. (zaption, 2016)



What is the molar mass of one mole of copper (II) nitrate, $Cu(NO_3)_2$?

Interactive Exercise

Use a table like the one below to help you find the molar mass of one mole of copper (II) nitrate.

Element	Atomic Mass (from the periodic table)	Multiplied by	# of atoms present in the compound	total mass of each element present in the compound
Copper	63.6	x		
Nitrogen	?	x		
Oxygen	?	x		
			Total Molar Mass	

1. List the elements found in copper (II) nitrate, $Cu(NO_3)_2$.
2. **Use the periodic table to determine the atomic mass of each element.**
Click on the buttons above to check your answers.

Fig.9: Texas gateway interactive exercise
Source : http://www.texasgateway.org/resource/moles-and-molar-mass

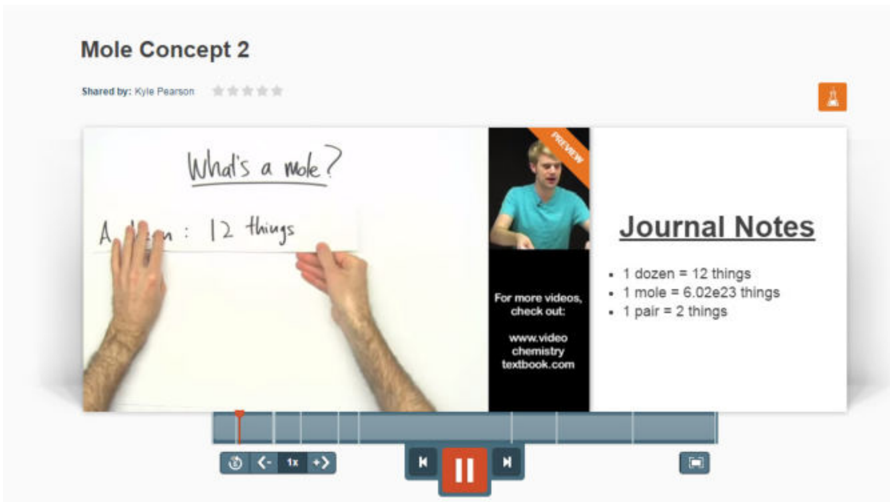


Fig.10:Mole concept in Zaption
Source : https://www.zaption.com/listing/56d5bb263cf097d043d8d628

Primary research

Focus of research

Difficulty due to the concept definition and formation

Why is this concept universally considered to be difficult ? Its formation in history, What difficulties arise due to the fundamentals on which it is based?

The textbook content and teaching style

How consistent is both ? Does the teachers follow the content ? Why or why not? What are the methods followed by the teachers to make the students relate to the concept? What are the confusing areas in the content?

Students cognitive ability and understanding the concept

What are the challenges for the students for learning the concept? Why ?

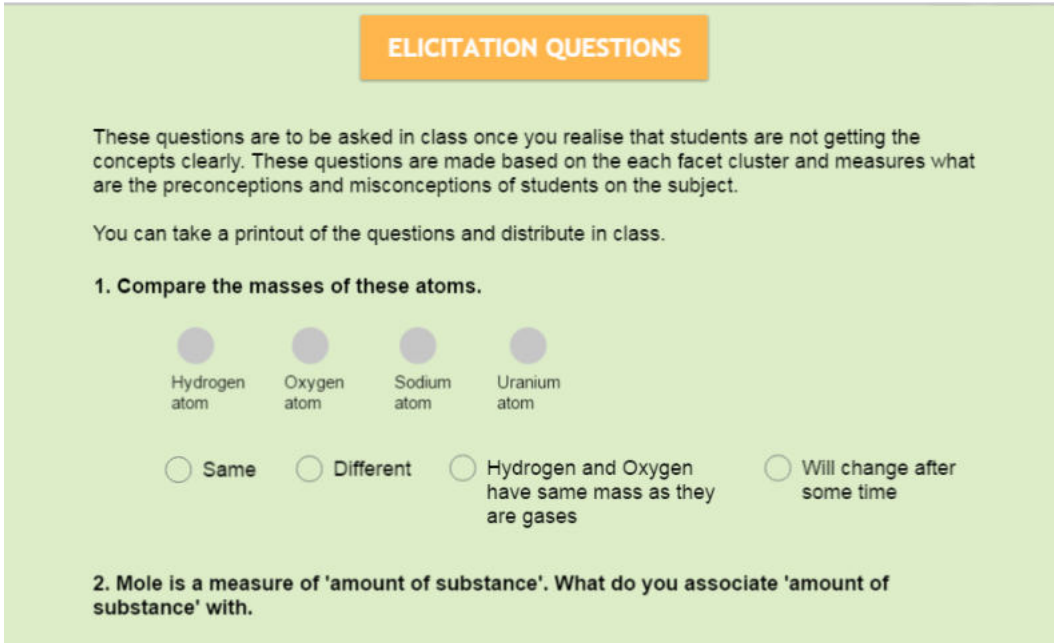
Activities

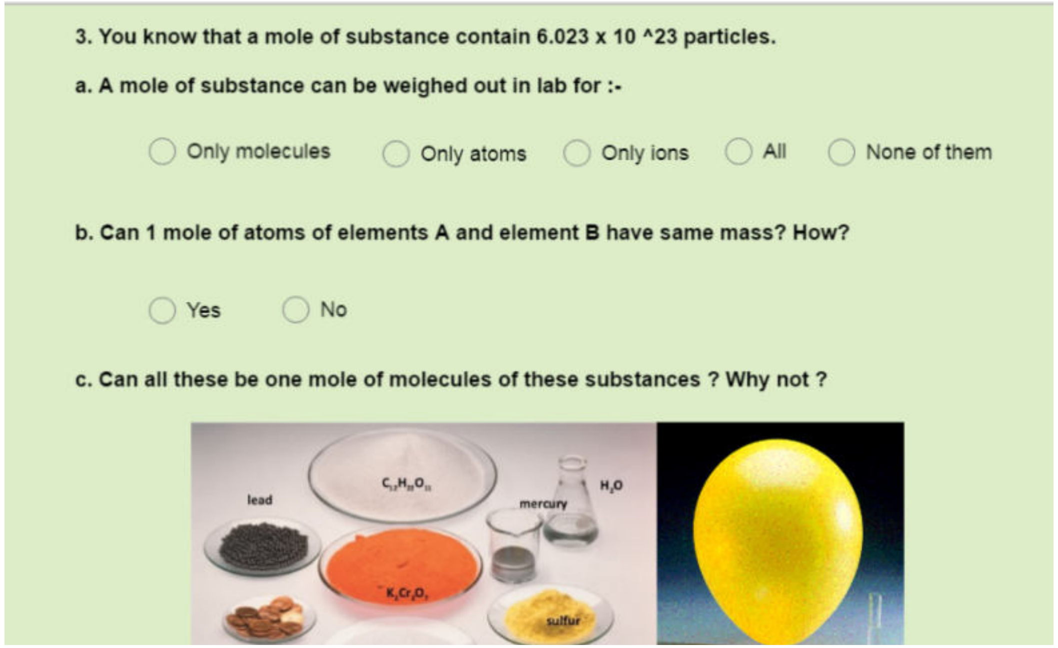
1. Teach mole concept according to the script

2. Elicitation questions were prepared and asked to 4 students in order to bring out the misconceptions in the students minds.

3. Showing videos - Khan academy and Ted Ed and listening to response.

Fig.11: A sample of elicitation questions asked to predict the preconceived notions within the students.
Source : Author





3. You know that a mole of substance contain 6.023 x 10 ^23 particles.

a. A mole of substance can be weighed out in lab for :-

◯ Only molecules ◯ Only atoms ◯ Only ions ◯ All ◯ None of them

b. Can 1 mole of atoms of elements A and element B have same mass? How?

◯ Yes ◯ No

c. Can all these be one mole of molecules of these substances ? Why not ?

Fig.12: A sample of elicitation questions asked to predict the preconceived notions within the students.
Source : Author

Fig.13: Interview with teachers
Source : Author

How do teachers teach ?

Important observations obtained from the user research are explained below.

Incremental vs Integrated[2] approach

The first notable finding is that there is a discrepancy between textbook and teacher's methods. Text book follows an incremental approach of learning with set rules and allocated time for each topic which is much more that what teachers can provide. Hence, the teachers follow a integrated approach. While an exceptionally good teacher with an integrated approach can give good results in a shorter time, most teachers find organising difficult in abstract concepts. Incremental approach has time constraints to cover such a long chapter. Moreover, the level of conceptual understanding in mole is found to be less in incremental approach due to 2 reasons. Mole is a nested concept and the structuring of class hours and the disconnect between concepts arising due to it. Hence the teacher have to start over again each time.

Hence, there should be some way in which students can keep up with teachings before hand.

Disengagement and lack of motivation

Lack of attention in class is a common concern in most of the science classes. Students more interested in lab and not in theory. But, when learning a long continuous concept, motivation is crucial. Activity based learning is always the best method to teach. An activity was conducted by a teacher to prove this :

Experiment : Students were taken to the lab and asked to weigh out 1 mole of common salt from scratch. The mistakes made and the regular feedback of teachers were helpful to students.

Giving visual feedback and feel of amount of substance and embodied interaction for simulating lab through games are hence good ways in which such problems can be solved.

Lack of emphasis on real world use

There is a lack of adequate knowledge about its future use. i.e., Stoichiometry and chemical reaction. Textbooks give examples about future use, but it remains as a theory and not used in applications other than math problems.

These examples can be shown as activity or stimulated before reaching the concept itself. An interactive video, telling a story about use of mole can be used.

Lack of important prerequisite – relative atomic mass

Activity : I taught about mole to a group of students by taking hydrogen atom as example. I explained to them how molar mass of hydrogen is 1g/mol, Sometime after this activity I asked them what is the mass of 1 hydrogen atom. Almost 90% of them tend to give their initial reply as 1 and later 1g.
Misconception : Atomic mass and molar mass are equivalent

2 Integrated approach of learning
Integrated learning incorporates multiple subjects, which are usually taught separately, in an interdisciplinary method of teaching. The goal is to help students remain engaged and draw from multiple sets of skills, experiences and sources to aid and accelerate the learning process.
(Reference.com, 2016)

The reason is thinking mole as an entirely different concept and the idea about its generation from relative atomic mass being not visually bonded to the students schema. Setting the base of relative atomic mass and gram atomic mass visually is very important

Confusion of students and teachers over whether mole is (mass/number/ amount)

'It is confusing' was the majority of answers from teachers for why this topic is difficult.

Activity : Asking students an open ended question What according to you is mole?

Misconception 1 : Mole is 'mass' of something

Misconception 2 : Mole is 'no. of particles or molecules'

Misconception 3 : Mole is 'Avogadro number'. This is the most frequent answer as everyone remembered the Avogadro number.

Mole as 'amount of substance' is not emphasized properly for atoms itself and hence there is a difficulty when molecules, multi atomic elements are introduced.

The major underlying reason was found out as both teacher and students were not able to visualize the micro property and macro property of mole in the same concept window.

Problem solving method of instruction

Typical kind of problems are made to be solved by the students from the second class onwards. Given 'x'g of O2, How many moles does it contain ?How many particles does it contain ? and vice versa

Classes are taught through increasing the level of problems ,This is not very effective , if teacher don't explain concept before or after the problems

At times, students find it easy to relate to mole concept once they know how to solve the problems.

The design solution is to go for a Reverse teaching style ; from problems to the concept.

Substance	Formula	Molecular mass	Gram molecular mass
• Hydrochloric acid	HCl		
• Sodium hydroxide			
• Sulphuric acid			
• Calcium carbonate	$CaCO_3$		
• Ammonium sulphate	$(NH_4)_2SO_4$		
• Sodium chloride			

Table 2.5

Atomic masses
H = 1
C = 12
N = 14
O = 16
S = 32
Cl = 35.5
Na = 23
Ca = 40

Mass of the sample element taken (g)	Number of gram atomic masses	Number of atoms present
• 60 g Hydrogen		
• 60 g Carbon		
• 160 g Oxygen		
• 1 g Oxygen		
• 50 g Chlorine		
•		

Fig.14: Problem solving - practice tables
Source : SCERT Kerala 10th standard textbook

Tables and diagrams are the most accepted and faster teaching method. Practice and pattern formation. But, Student find difficulty once patterns are rearranged.

Pattern formation is an effective method, but different patterns should be used to avoid confusion

Teaching method - Analogies

The concept is taught in ncert syllabus is through the definition,where as SCERT through experiments and examples

1. counting coins in bank
2. Counting grains in shops

Story telling is another effective mechanism for keeping the attention of the students. Use of analogies help in relating to the amount of substance. All this should be used for devising a new and better solution.

New vocabulary

There is a lot of new vocabulary with similar phonetics

Molecule Mole

Molar volume

Molar mass

Molar molecular mass

Molar atomic mass

Atomic mass atom

The design solution is to show them visually and relative to each other and using mnemonics.

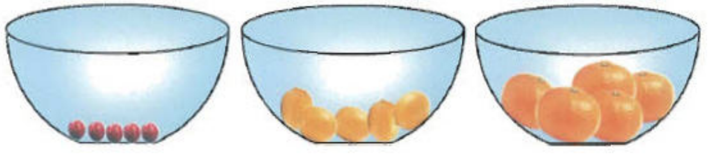


Fig.15: Use of analogies of fruits to explain atoms
Source : SCERT Kerala 10th standard textbook

How do children learn ?

The various issues that were found out regarding students difficulty in learning the concept were as follows.

Lack of formal operational ability in students

Mole concept is a formal operational concept and it should be taught in 4th and final stage of Piaget theory (children of 11 years and above). Some students don't reach this stage mentally at this age also. Such students should be taught using cues from concrete operational stage. (Piaget : simply-psychology, 2016)

Lack of proportionate thinking.
Lack of imagining large number of particles and small masses
Use of maths i.e.,

Difficulty linking operations needed to solve,problems with more than one step problems and memorizing arithmetic rules.

The design solution is to replace verbal proportions through diagrams and larger elements. An integrated approach showing all these properties and its relationship should be devised. The atomic model of molecules and multi atomic elements should be shown to the children from the initial stages of chapter 'atoms and molecules'.

With a topic like mole concept often the problem other than the above is not inability to learn, it's a low interest rate . If the material is too simple, the student may be bored. If it's too difficult, the student may become frustrated. In both cases, the opportunity to learn with an aha moment is missed.

Fig.16. Group discussion with students of GHSS Koduvally. Source : Author

Hard spots

1. Students do not know why it is taught.

Just like the fact that teachers were not aware of the historical changes in mole concept, they didn't give importance to why mole concept was introduced in the first place - To measure atoms and molecules as they are small in size.

The ultimate and major use of mole concept is in stoichiometry. This is not introduced to the students. The whole concept itself can be taught as doing reactions and exploring the various combinations.

2. Lack of important prerequisites

It is important to know what is the students level in the subject that leads to the topic, to help them improve from there. As mole concept is a set of nested concepts, it is important that prerequisites are understood. The major prerequisite required are atomic mass and relative atomic mass, atomic model, atomicity.

3. Misconceptions or P-primes

The major misconceptions identified from primary research are

1. Mole is a term used only to represent the amount of substance of molecules.

2. As the value of molar mass and atomic mass is the same for an element, assuming that the quantities are also the same. This is due to the wrong way of usage of language i.e., representing molar mass in 'g' rather than in 'g/mol' and not knowing the relation between relative atomic mass and molar mass.

3. As one mole of various substances look very different in quantity, how can the 'amount of substance' be same. Assumption that number of particles also might be different.

4. In a balanced chemical reaction, assuming that the coefficient will work for masses of the substances also. For example, for the reaction $H_2 + Cl_2 = 2HCl$, assuming that 1g of H_2 will react with 1g of Cl_2 to give 2 grams of HCl.

4. Lack of link between Mole , atomic model and other parameters like mass, volume

This can be easily understood from their difficulty in solving simple conversion problems. The lack of visual knowledge of mass, volume and atomic model is the reason.

5. Language ambiguity

Usually when teacher use the term mole, they use it alone without referring to mole of what, whether it is mole of atoms, molecules, ions, electrons. According to them mole when used alone always imply mole of molecules, which is a cause of confusion, wn mole of atoms come in to context. Example : Mole of atoms of H2 and Mole of molecules of H2.

Another issue was the term 'Amount of substance' and what students think it is. Most of the students identified it with mass, as that is how amount is measured in shops. But,according to mole concept, before jumbing to mass students should identify amount of substance with number.

6. Lack of imagining small size of atoms and magnitude of avogadro number

This is a well known issue, originating from the microproperty of atoms. Students tend to understand bigness through actual numbers but not through powers. Powers of ten seems to reduce the sense of bigness of numbers like avogadro number.

Restated Project Brief

Product brief

Design an interactive tool that aids students in self learning mole concept through activities

- to reduce the misconceptions
- to practice and learn the prerequisites

Context of usage

1. As a self learning tool downloadable from the internet

2. The tool is suggested by the curriculum and shared by teachers to students to practice and self learn

Target user

9th and 10th standard students

Final Learning Objectives

Compare with examples atomic mass, molecular mass and relative atomic mass of substances.

Visualize and describe that a mole is a group of 6.022 X 10^{23} particles and its magnitude.

Define and calculate molar mass of any element/ compound and it is same as its atomic mass but unit is changed from ‘u’ to ‘g/mol’ (gram).

Compare the amount/magnitude of molar mass of different elements in relation with relative atomic mass.

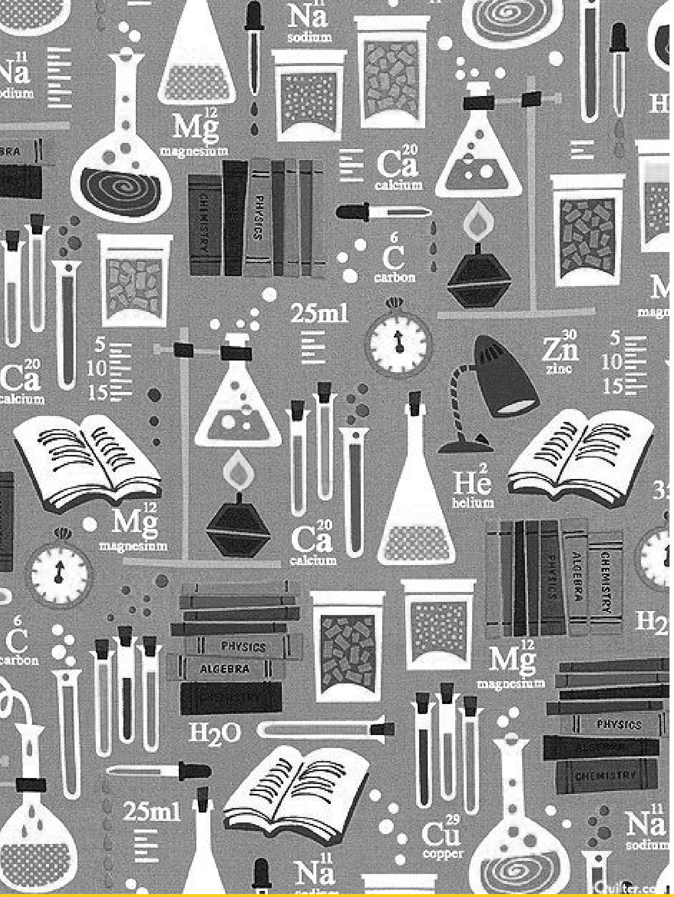
Understand why mole is taught in chemistry.

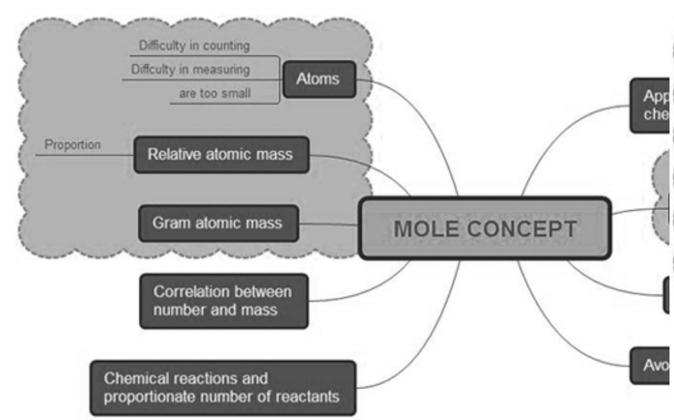
Illustrate with examples Molar volume in case of gases.

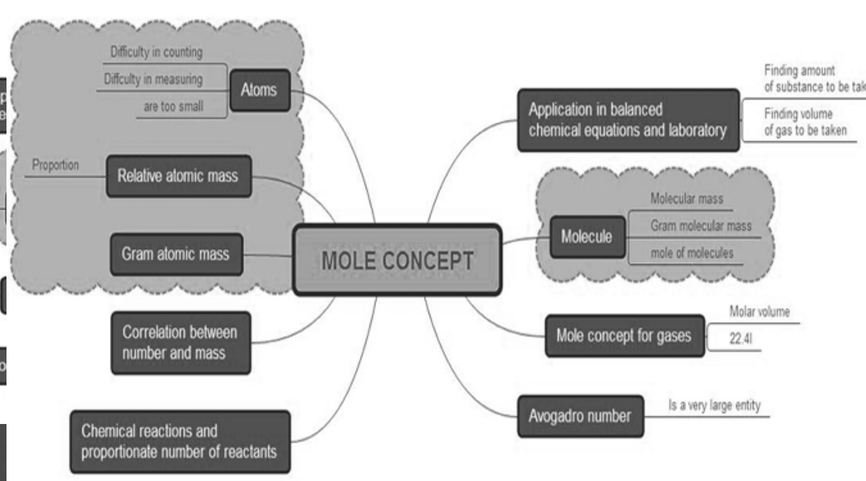
Compare mole and molar mass in case of mono, dia and poly atomic elements.

Other objectives

The product should reduce disengagement from topic and flow.




Difficulty in counting
Difficulty in measuring
are too small
Atoms
Proportion
Relative atomic mass
Gram atomic mass
MOLE CONCEPT
Correlation between number and mass
Chemical reactions and proportionate number of reactants
App
che
Avo


Difficulty in counting
Difficulty in measuring
are too small
Atoms
Proportion
Relative atomic mass
Gram atomic mass
MOLE CONCEPT
Correlation between number and mass
Chemical reactions and proportionate number of reactants
Application in balanced chemical equations and laboratory
Finding amount of substance to be tak
Finding volume of gas to be taken
Molecule
Molecular mass
Gram molecular mass
mole of molecules
Mole concept for gases
Molar volume
22.4l
Avogadro number
Is a very large entity

Ideations

Tackling the various hardspots and misconceptions, systematically is the first step to ideation. Hence, Ideas were generated in different ways. 1st --Activity scenarios were designed for each of the specific problems listed for mole. 2nd -- Brainstorming random ideas for activities that helps learn mole. two explorations were taken forward. One focussing on visualizing and exploring the bigness of mole and other based on activity levels solving the nested concepts of mole.

Context of use

- Should supplement the current textbooks and activities.
- Self learning application without teacher aid.

Medium

- Interactive video, Animations.
- Digital or board games
- Interactive Installations

Visualize concept

- Everyday metaphors
- Game environment
- Storytelling

Engage users

- Narration from childs point of view
- Game levels
- Trial and error learning
- Activity oriented learning

Misconceptions

- Identify misconceptions
- Forming and breaking them.

Ideations

1. Students do not know why mole is taught.

To be learnt : The mole is important because it allows chemists to work with the subatomic world with macro world units and amounts. Atoms, molecules and formula units are very small and very difficult to work with usually. However, the mole allows a chemist to work with amounts large enough to use.

A mole of something represents 6.022×10^{23} items. Whether it be atom, molecule or formula unit.

Defining the mole in this way allows one change grams to moles or moles to particles. Even though you can't see the particles.

Learning Objectives

1. Students should know that mole is introduced in chemistry for measuring reactants and predicting the products in chemical reactions in laboratory and for stoichiometry.

2 Students should be able to calculate amount of reactants and products in real world reactions using moles.

Idea

A scenario was devised in which the student is given real world examples of a reaction happening in the industry and he has to perform certain activities using the reaction, which makes him aware that a wrong proportion of the reactant can lead to wastage of chemicals in large amount and hence, proper measurement is very important.

In the given scenario, the reaction of hydrogen and chlorine to form Hydrochloric acid is used. The student is asked to assume a wrong concept that he is able to manipulate the number of molecules used for the reaction. After the end of the activity this assumption is contradicted saying it is difficult to count molecules as they are small.

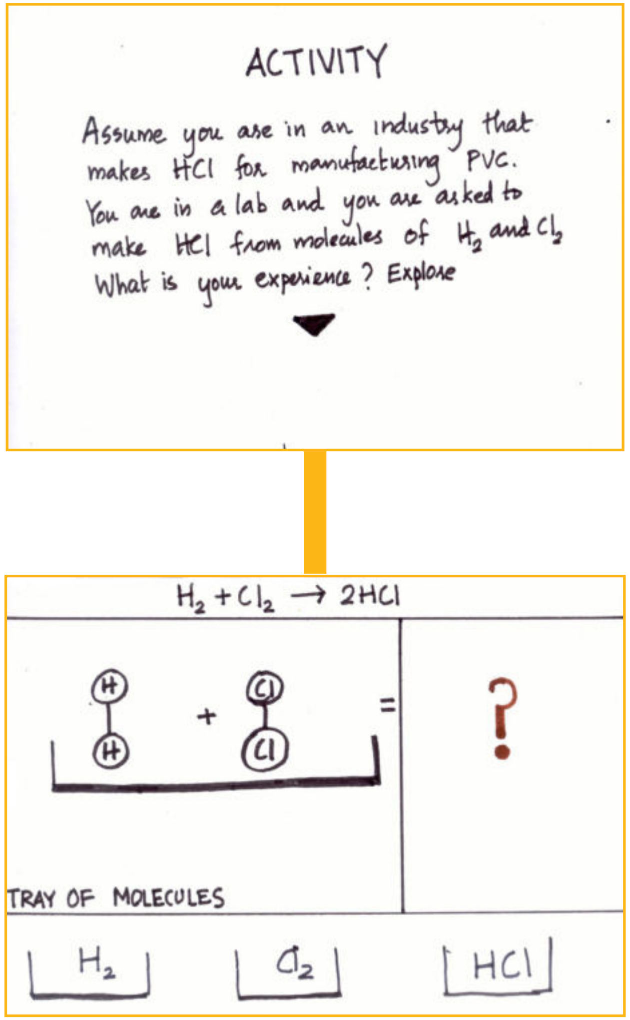
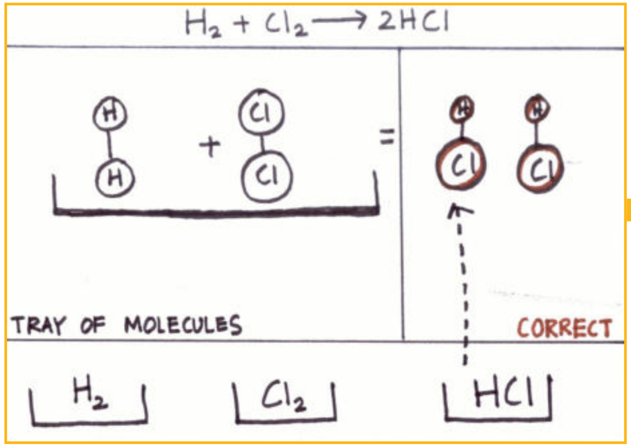
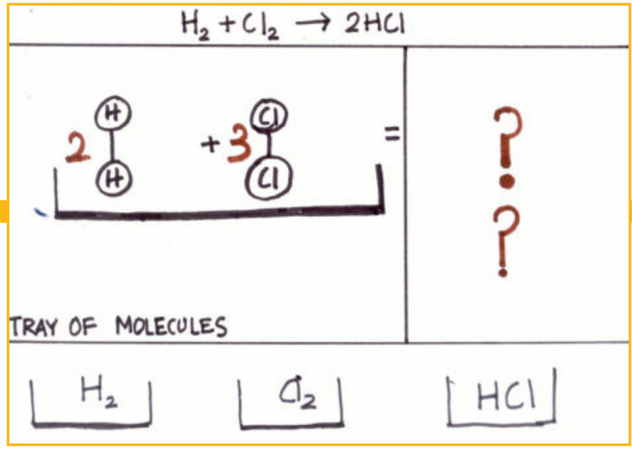
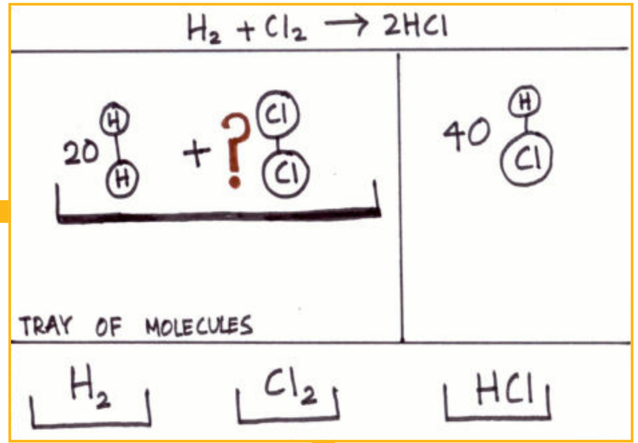
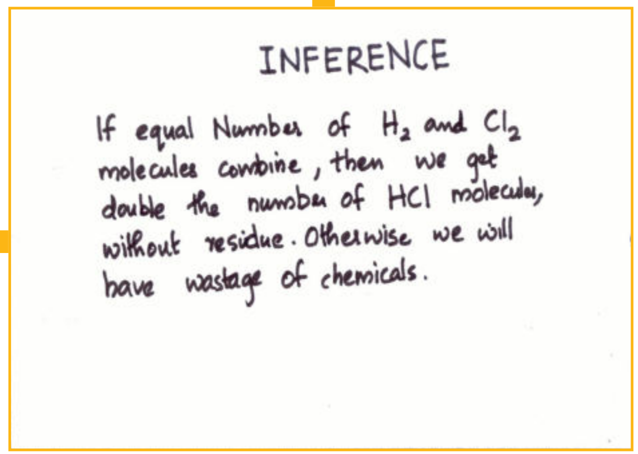


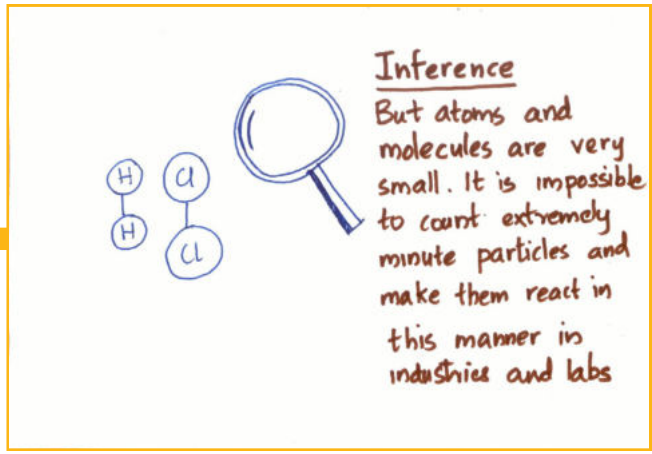
Fig.17: Scenario : Activity for student to learn the reason mole was introduced, with an activity.
Source : Author

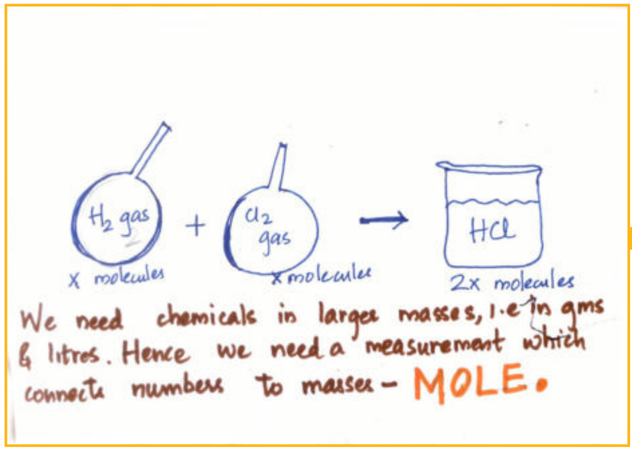

$H_2 + Cl_2 \rightarrow 2HCl$
H
Cl
=
TRAY OF MOLECULES
CORRECT
H_2
Cl_2
HCl


$H_2 + Cl_2 \rightarrow 2HCl$
2
+3
=
?
?
TRAY OF MOLECULES
H_2
Cl_2
HCl


$H_2 + Cl_2 \rightarrow 2HCl$
20
+?
40
TRAY OF MOLECULES
H_2
Cl_2
HCl


INFERENCE
If equal Numbers of H_2 and Cl_2 molecules combine, then we get double the number of HCl molecules, without residue. Otherwise we will have wastage of chemicals.


H
Cl
Inference
But atoms and molecules are very small. It is impossible to count extremely minute particles and make them react in this manner in industries and labs


H_2 gas
Cl_2 gas
HCl
x molecules
x molecules
2x molecules
We need chemicals in larger masses, i.e in gms & litres. Hence we need a measurement which connects numbers to masses - MOLE.

2. Lack of prerequisites

The major prerequisite that is conceptually difficult is relative atomic mass and its relation with mole. This is what I am trying to tackle with ideas.

Learning Objectives

1. Students should understand that atomic mass is a relative quantity. Atomic masses of elements are calculated relative to each other

2. Students should be able to define what is 'u' and what is relative atomic mass.

3. Students should explore the correlation between number and mass.

Misconceptions

1. Atomic mass is absolute and is larger than real as it is a whole number

2. Atoms are all the same with similar mass.

Idea

This concept is significant as the atoms being different in mass is the underlying reason for amount of substance to look different and weight different which is the core misconception in mole.

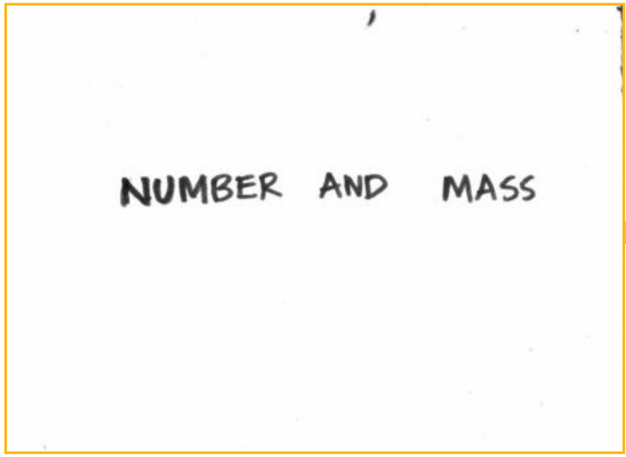
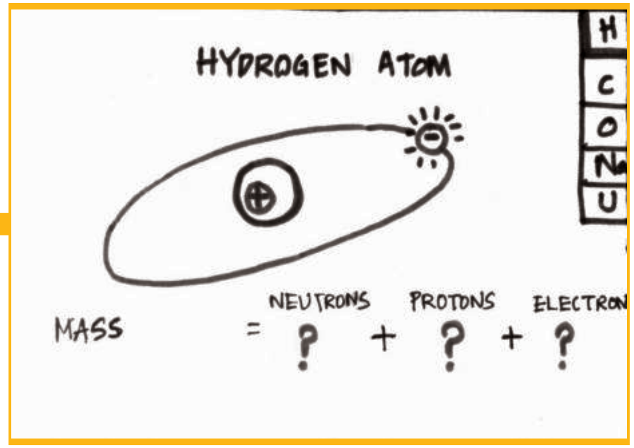
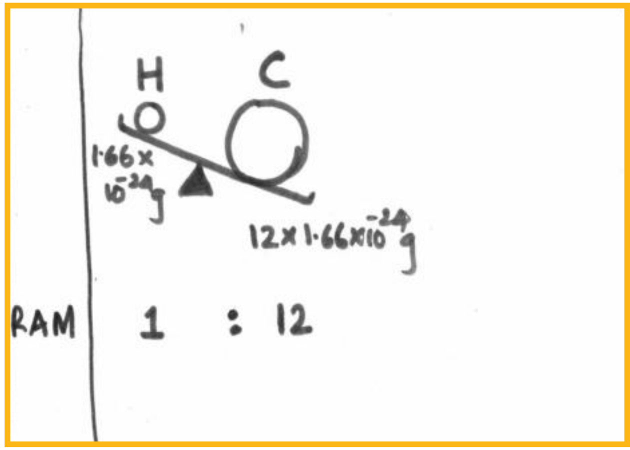


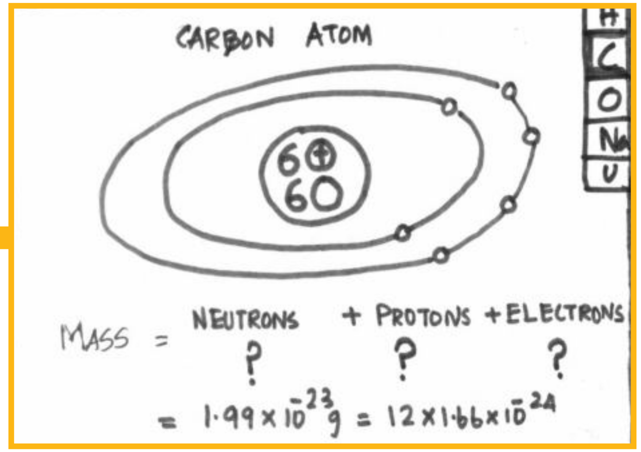
Fig.18: 1. Scenario : Activity for student to learn relation between number and mass
Source : Author



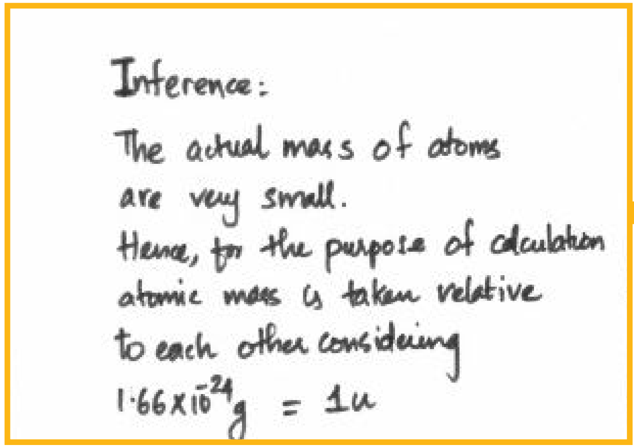
2. The exploration starts with an activity from the smallest atom - hydrogen and the student can actually calculate the atomic mass from mass of e,p, and neutrons.

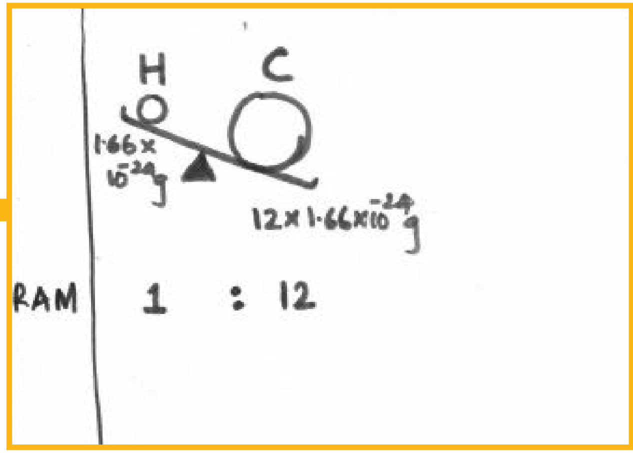


3. Student realizes it is not '1 as known, but a very small quantity which is taken as u for easier calculations

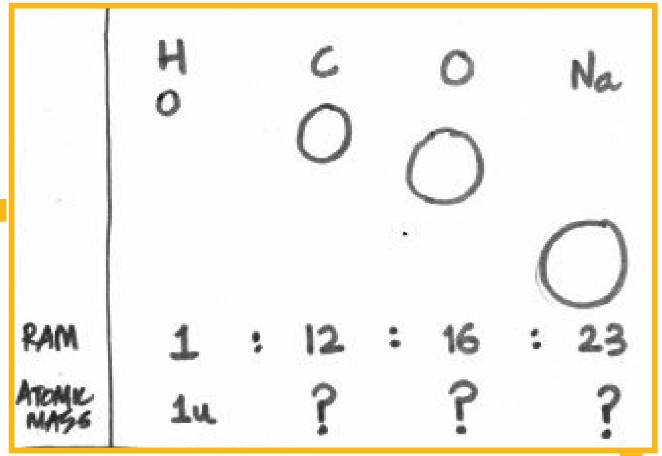


4. This activity is continued for other elements to find were the u in atomic mass comes from.

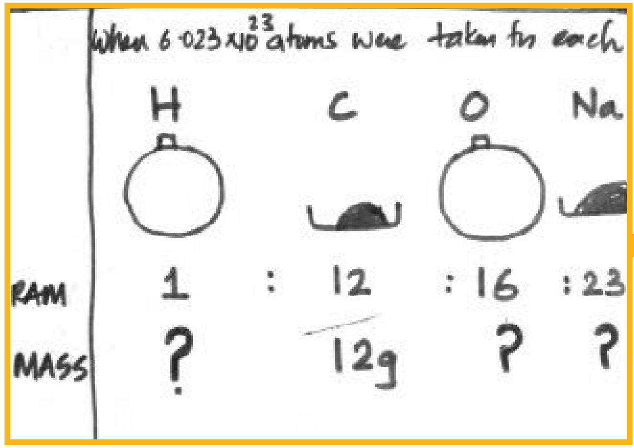




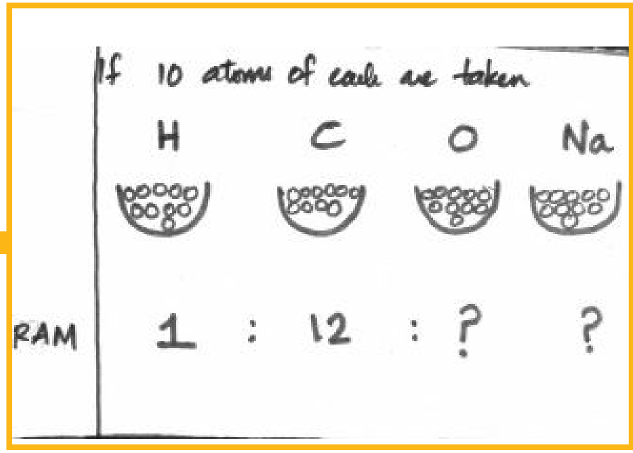
5. Visualizing relative atomic mass

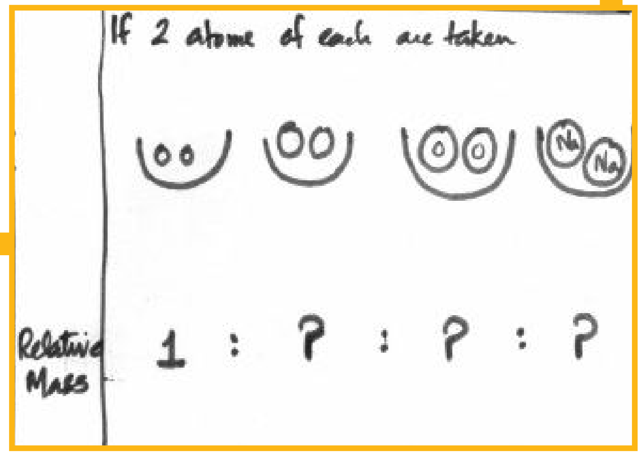


6. Prompting students to find atomic mass



7. How 1 mole has mass equivalent to relative atomic mass.





8. If equal numbers of elements are taken masses will be proportional as relative atomic mass

3. Mole and misconceptions

1. Misconception : As one mole of various substances look very different in quantity, how can the 'amount of substance' be same. Assumption that number of particles also might be different.

Solutions.

1. Exhibition of amount of substances

Weigh out one mole of available substances (elements and compounds) from a lab and exhibit it in front of the students for an activity. For gases that can't be weighed, take containers that corresponds to their molar volume. The substances that can be taken are namely, H_2O, O2, NaCl, Sugar, Iron, Copper, Aluminium etc. Instead of taking the actual form of the substance, it can be a day to day object that we see, like chalk or nails for iron.

Give them a weighing machine and a way to find volume of the container and ask them to find out how many particles will be there in each and which one has more? (like in figure)

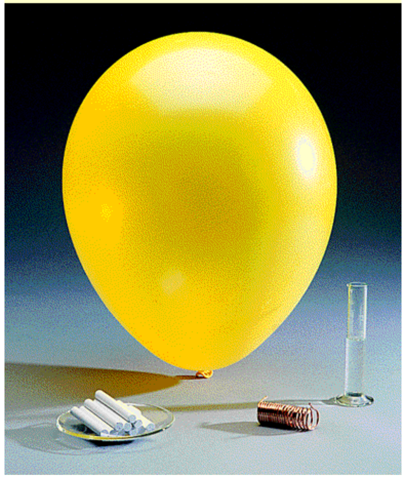
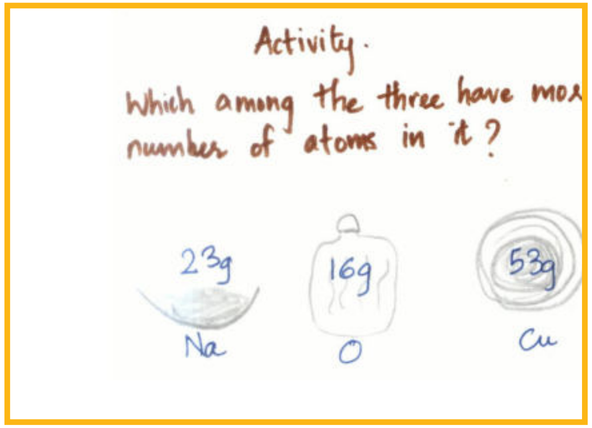


Fig.19: Amount of substance in 1 mole
Source : http://www.mhhe.com/cgi-bin



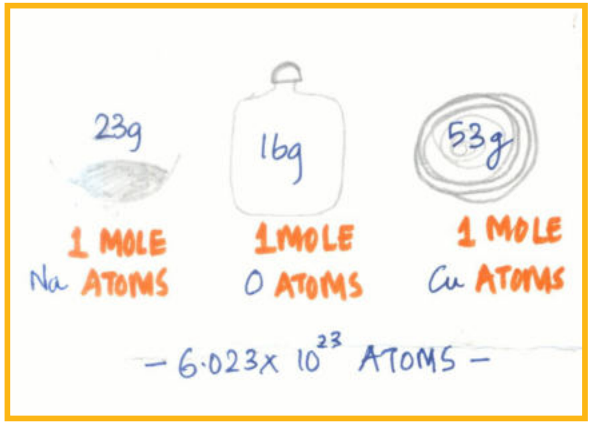


Fig.20: Question students on misconceptions on mole
Source : Author

2. Moles are only for molecules

A mole of all substances contain 6.023 x 10^{23} particles of that substance in it. i.e. even there is mole of ions, mole of electrons and protons etc.

Solution :

1. Provide an explorer that shows moles of ions, electrons and protons along with the rest.

2. Do not use term 'mole' independently, but use it along with the substance. i.e., It is mole of hydrogen atoms , not a mole of hydrogen.

3. Using real world questions to ponder mole.

a. You are thirsty after work. You bought 1 litre mineral water for 18 Rs. How much did one molecule of mineral water cost you ?

b. If your bike was made totally of Iron, How much moles of iron would have been used to make your bike?

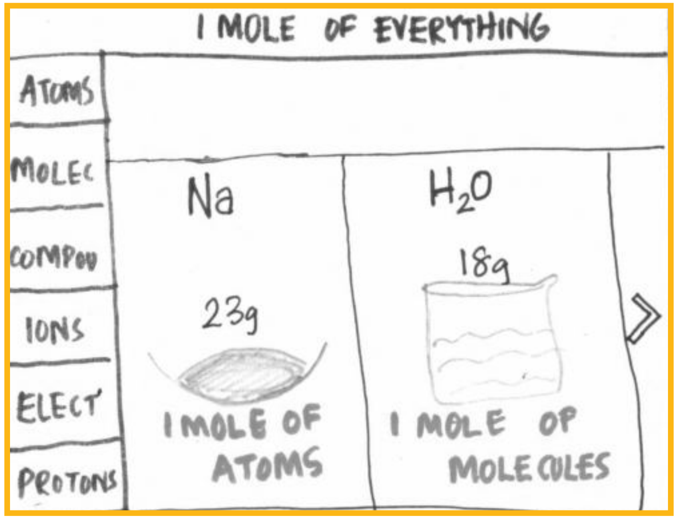


Fig.21 : The mole explorer should also show mole of ions, electrons and protons.

4. Language confusion when saying mole of atoms and mole of molecules for all atoms.

Solution : Make students do problems where they have to identify the mole of the constituent of compounds.

The H_2O installation

Corridors and water points in schools are areas where children tend to spend time in groups discussing about class and other activities. This space can be utilized effectively for an installation about mole. One of the major obstacles for students in learning about the concept is the inability to visualize the macro property of Avogadro number in a mole of substance. This should be learnt by the children through experimenting and visualizing the amounts of mole in various elements and compounds. The best place to do so is to take the children to the lab and make them weigh out chemicals in the proportion of mole. But the time frame of academic curriculum and lack of lab infrastructure do not let this happen. And interacting with these chemicals need special care and attention.

So, the idea was to use water, a commonly known compound to simulate an installation on moles. It is an experimental and integrated approach to show correlation between mass, number of particles, amount and moles using the well known compound water.

Installation is made of 3 components-

a set of dispensers that dispenses allotted count of water molecules when children press the button

An interactive panel that houses a water container to which the moles are dispensed, digital displays that updates the number of molecules, moles, mass of the quantity in the container and the buttons for the children to select the right dispensers.

A screen to display additional information and badges to the children who makes a mole.

There are 4 dispensers ranging from 1 molecule of H2O to 1 lakh molecules. There is a custom dispenser which allows children to dispense the water they have in their bottles.

Additional features are an higher version of the installation in which 2 children can dispense hydogen and oxygen molecules simultaneously to build water.

The students are not given any instructions in the beginning and they are let to find out themselves.

Learning Objectives

This idea corresponds to parts of the following objectives from the learning objective set.

1. Visualize and describe that a mole is a group of 6.022×10^{23} particles and its magnitude.

2. Define and calculate molar mass of any element/ compound and it is same as its atomic mass but unit is changed from 'u' to 'g' (gram).

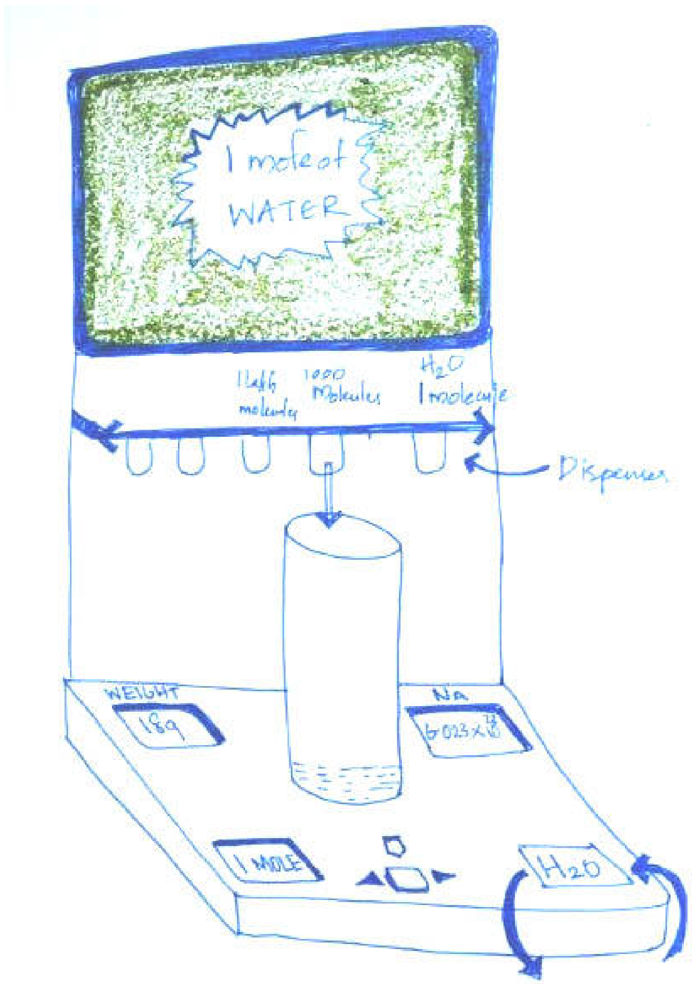


Fig.22: The H_2O installation
Sketch : Author

The selling point of the idea is that children learn through fun activity and without knowing that they are being taught a concept. The idea can be prototyped as a tangible installation or a digital touch software.

Problems

1. Only one element or compound can be learnt at a time with the installation

2. Dispensing molecules of a compound will mislead about the size of the molecules and atoms

3. Comparison between elements (mono atomic and poly atomic) and other molecules is not possible

4. Not scalable

5. The physical installation might actually become messy with the custom dispenser

Card games for mole concept

When asked teachers about the attention levels of students in their class, teachers replied that it depends on the task being taught. If it is a lab or a group activity or a game , students are very interested. Card games can be an add-on method teachers can use to reinforce mole concept in students minds.

Method : After teaching the concept, the students in the class are divided into groups. Each group will be given a name (1,2,3) which corresponds to mole number they are entitled to.

The set of cards comprises of elements and compounds in different masses. The groups should collect cards of elements/ compounds corresponding to their name. The team that collects 20 cards first will be the winner of the race. The corresponding atomic or molecular mass is given on the card.

A sense of proper teamwork is required in winning the race as one student in the team should do the job of calculating how many moles it amounts to.

The major function is practice and feedback to teachers. Interest and attention adds to the atmosphere of class.

Learning Objectives

Compare mole and molar mass in case of mono, dia and poly atomic elements.

Problems

Constant assistance of teacher is required to manage the game

The game do not teach the concept , but reinforces it. The students who did not understand the concept will be reluctant to participate in the game. This is the basic disadvantage of the card game as it teaches practice .Mistakes in calculation and selection of cards and a fight for getting the card can be reduced by rotating the cards around group.

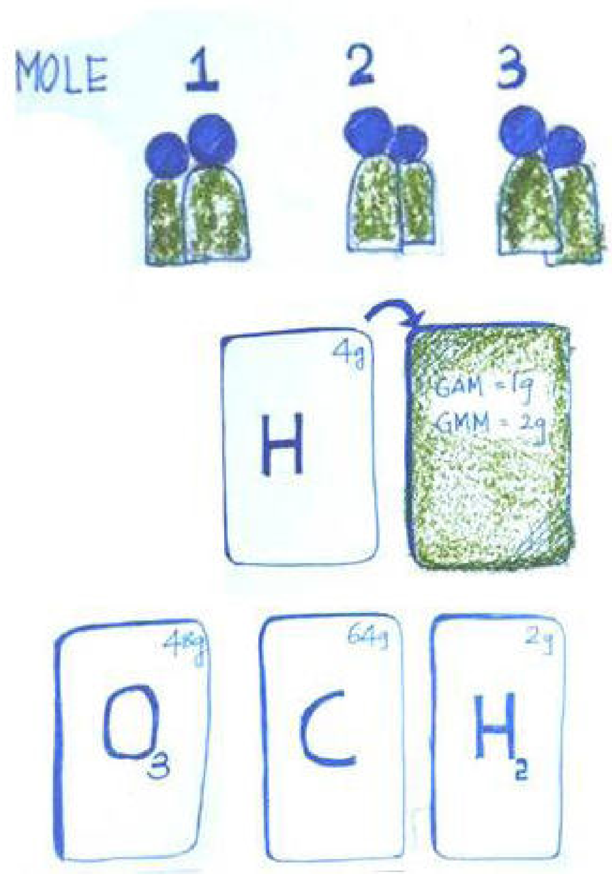


Fig.23: The card games for collecting mole

Mole visualizer

The core issue in understanding the basic principle of mole is identified as the inability to visualize both macro and micro properties of substance and lack of visualization skills.

Teachers sometimes use molecule visualizers in high school classes and this is a very good attention factor in students. They use it in senior classes which help students make and manipulate molecules. But the relationship of mole has never been introduced in the visualizers.

The various techniques used in the mole visualizers:

1. Metaphors to show the quantity occupied by a mole of solid and gas and why it is different.

2. Comparison between atom, molecule and mole of the element

3. Compare moles of two elements and understand why they are different in mass.

4. Moles of daily objects like sand,apple vadapav etc to generate interest and understanding

4. It can act as a directory of elements and students can add to it with their experiments in lab.

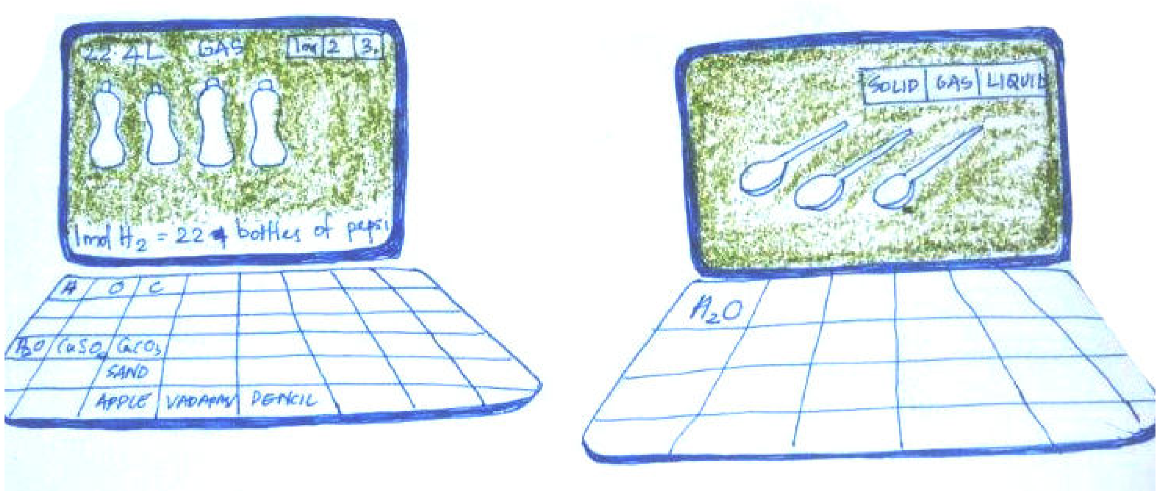


Fig.24 : Visualizing a mole as relatable entities
Sketch by Author

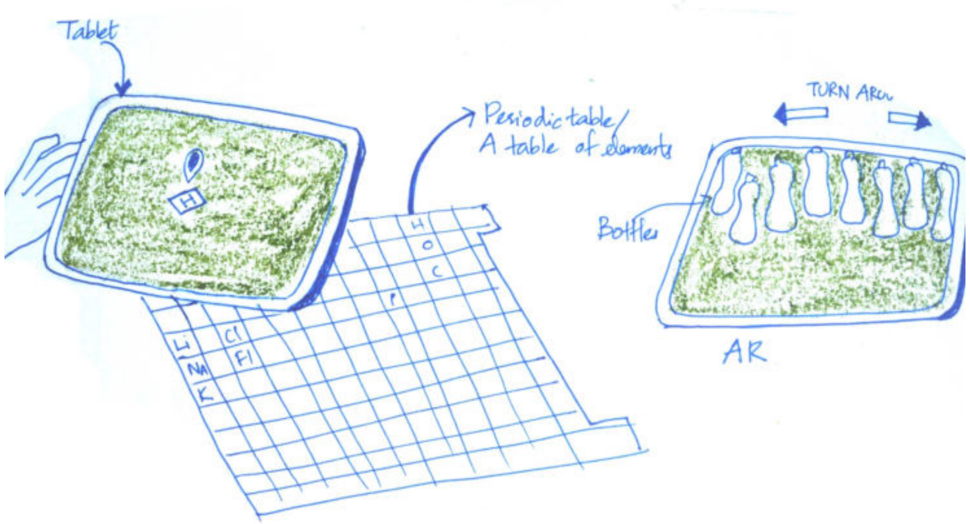


Fig.25: Visualize and augment over periodic table

Technology

Various mediums were thought of for the idea such as using augmented reality application on periodic table, mixed reality application by moving pegs on a periodic table keyboard to visualize mole.

Inference

Comparing all the ideas of activities that students can do to develop the concept of mole, the final idea of visualizing mole at various levels was taken forward as a concept 'Molescope'.

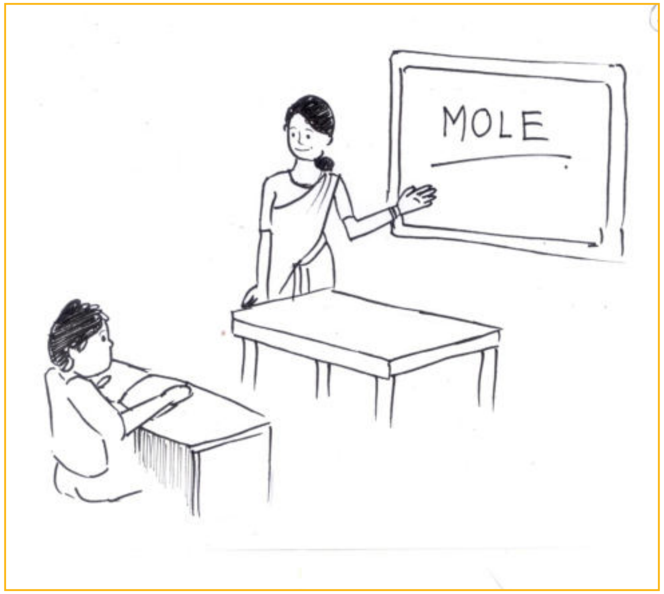
Concept 1 : Mole scope

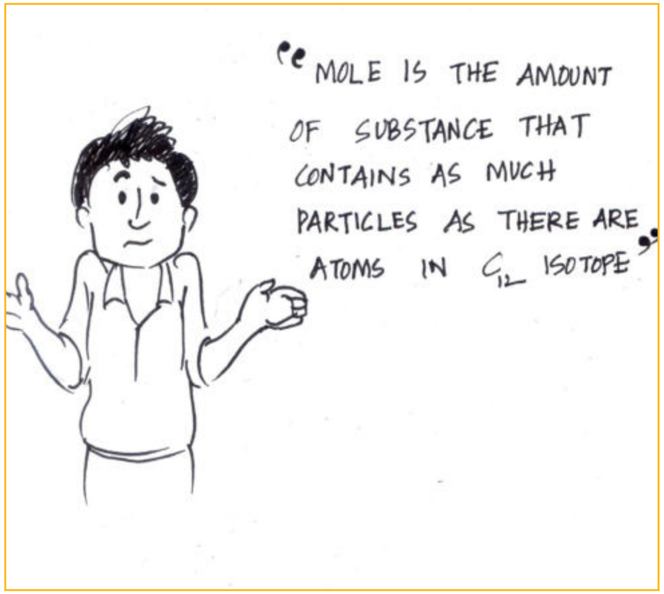
The concept is called 'Mole scope ' a device that dwells on exploring the macro and micro worlds of chemistry starting with the real world .The concept is derived from a students fantasy point of view recollecting the pensieve from Harry potter where harry drowns into another world to have a very unique experience and the video clip by Eames ' The powers of ten' which beautifully explains powers to ten through distances in the universe.

The application will be installed in the smart classes of schools, where it can be viewed by the students whenever they want. The application comprises of an environment that is introduced to the child with elements and molecules.

A problem and solution scenario of Mole scope is explained as an experience of a 9th standard boy called Rohan.

Problem Scenario



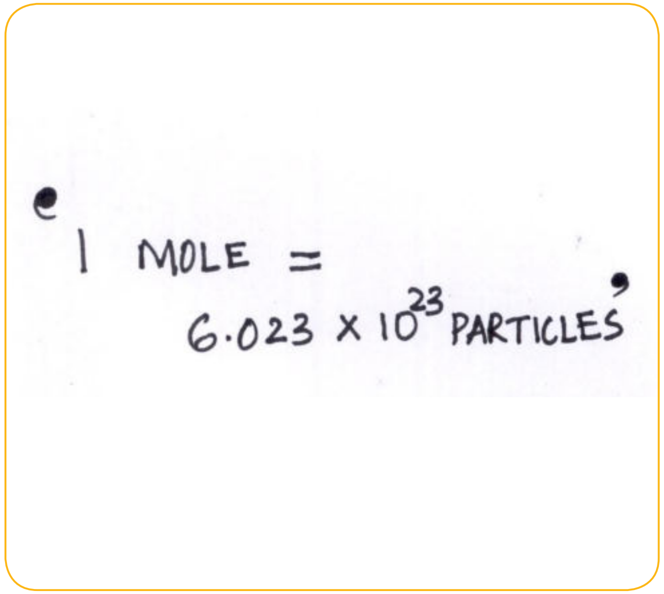


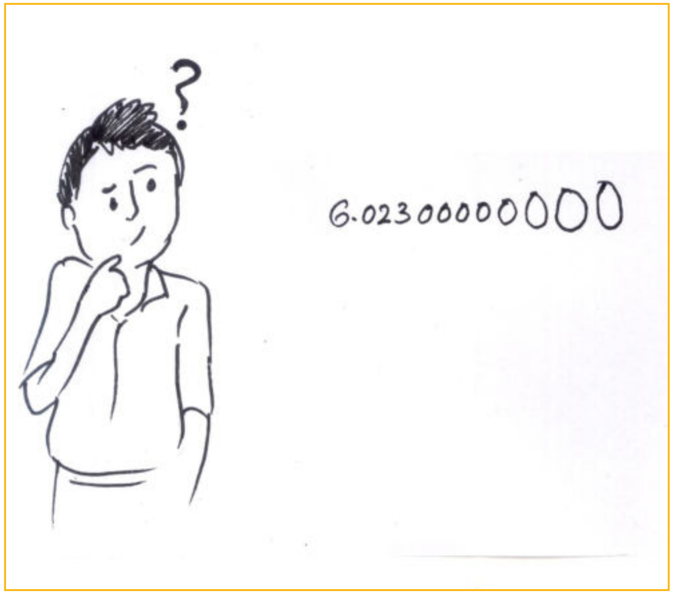
Rohan is a fun loving 9th standard student in a CBSE school

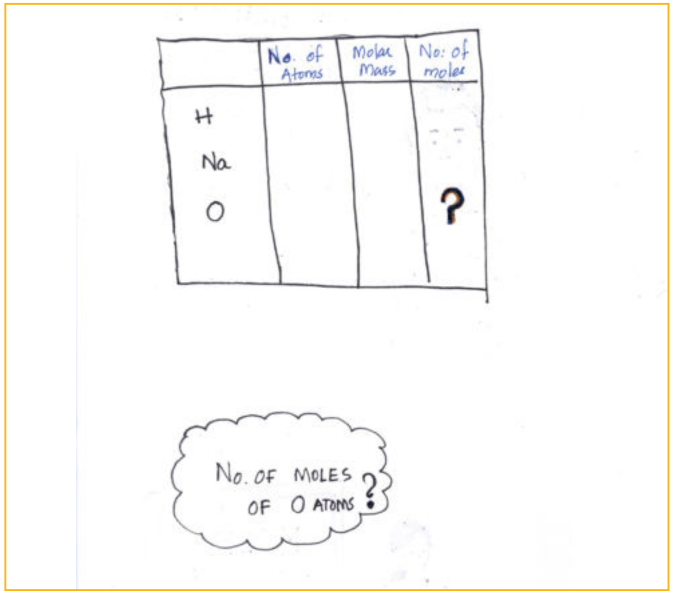
Today, chemistry teacher taught a new topic called MOLE

The teacher started with the definition which was very confusing for Rohan.

Fig.26 : Problem scenario
Sketches by Aparna Kulkarni and Author







Rohan remembers Avogadro, but the number really confused him a lot .

The teacher also gave problems to solve using tables, which he somehow managed to complete . Rohan couldnot understand mole even now.

Conceptual model

The basic conceptual model is to connect between the macro and micro world of mole chemistry through an animation and the story is told about 4 specific substances in the environment. Each of these substance cover a specific category of chemical substance namely, mono atomic element(Fe), diatomic element(Oxygen), Compound(Water), Macro substance(sand). In order to understand the macro property of Avogadro number, the category called macro substance uses sand grains and explain how big 1 mole of sand grains will be.

Context of use

The intended use was as virtual reality application with a head mounted display. But, that scenario might be difficult in all schools of my research. So a desktop application with touch or mouse is designed. This can be installed in the smart classrooms of schools and kept in planetariums or science centres to be accessed by students individually to explore.

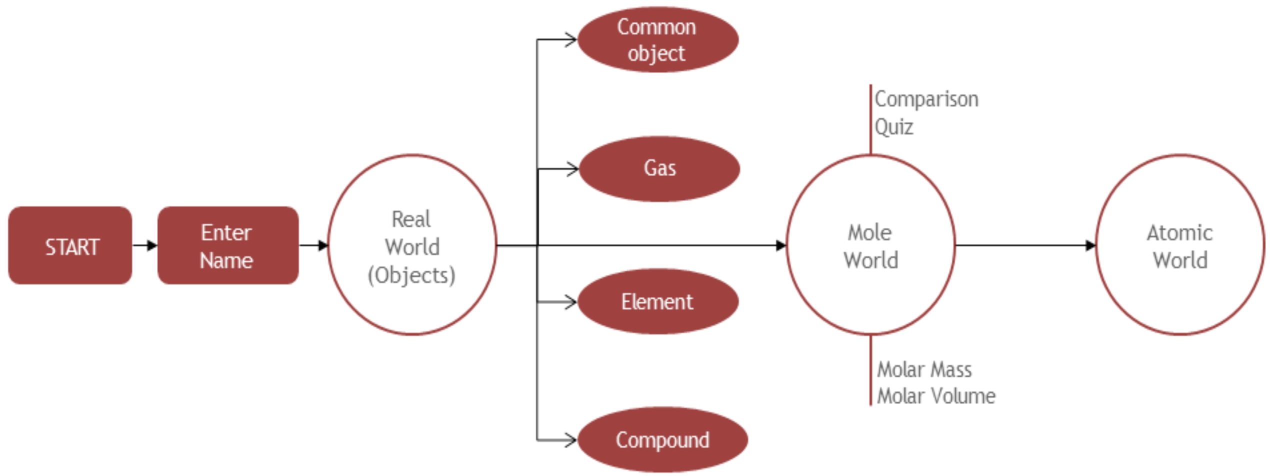
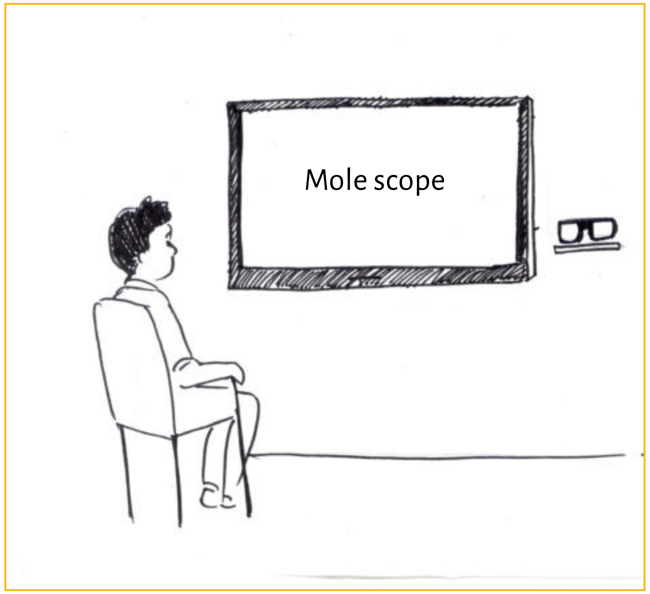


Fig.27 : The conceptual Model of Mole scope

Mole scope - Solution scenario

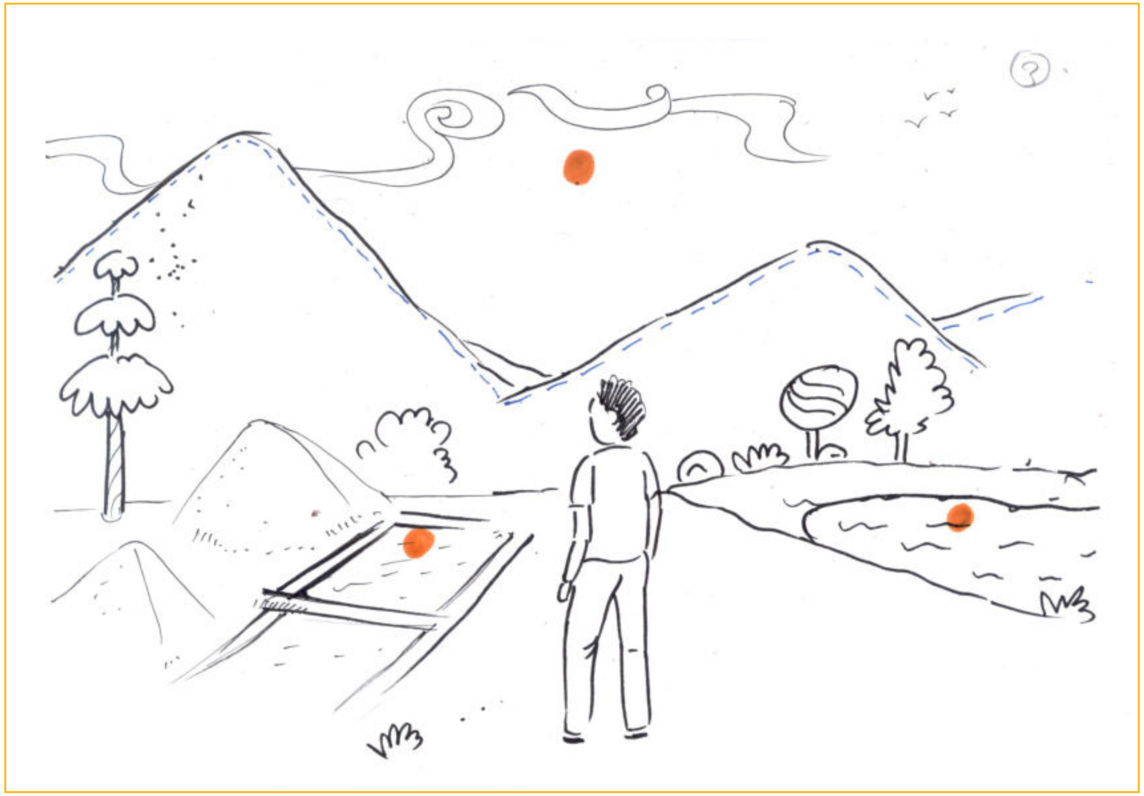
The following scenario shows the experience the student is intended to have once he is using the product. The current scenario is only for his journey when he explores water as the molecule. Other scenarios will be explained in the design section.

Rohan is quite fond of smartclass in his school. He gets to play with lot of interesting softwares. He decides to go to smartclass during his leisure time.

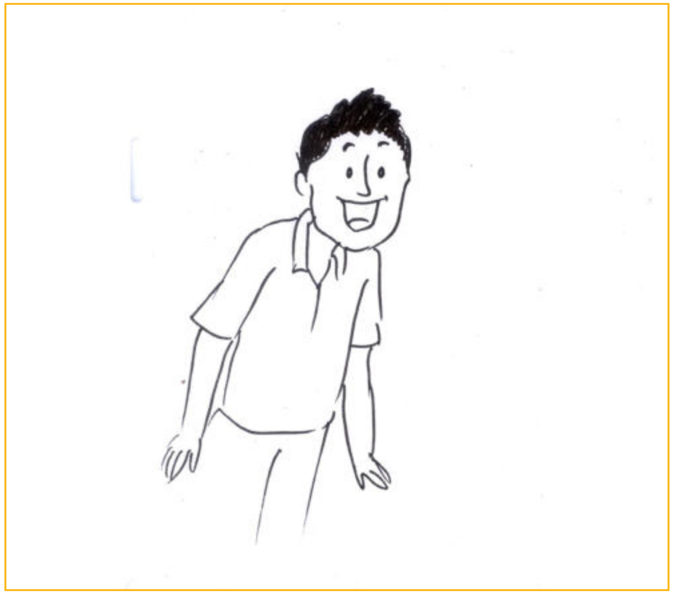


He sees a new software Mole scope. He is excited as he has to put on the 3D glass for using the software.

Fig.28 : Solution scenario
Sketches by Aparna Kulkarni and Author

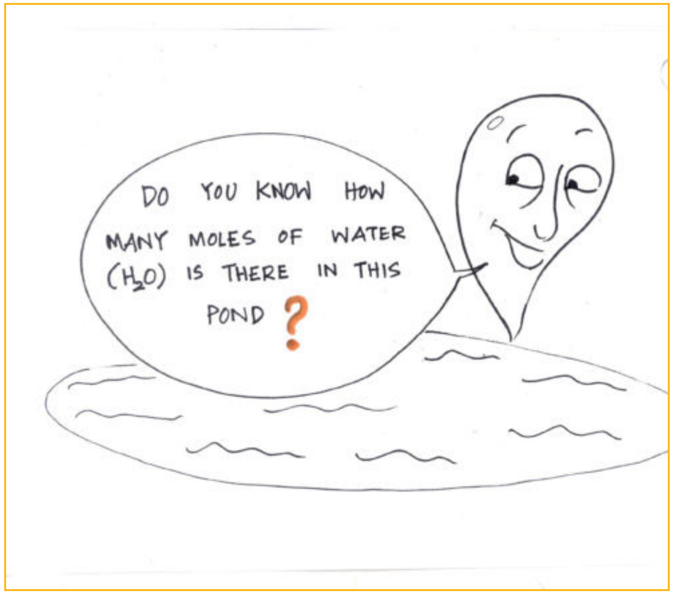


This takes him to a new fantasy environment. In this world , all seems to be little different . There is a pond , salt planes, weird clouds and trees. Rohan can see certain blobs hanging over in the air.

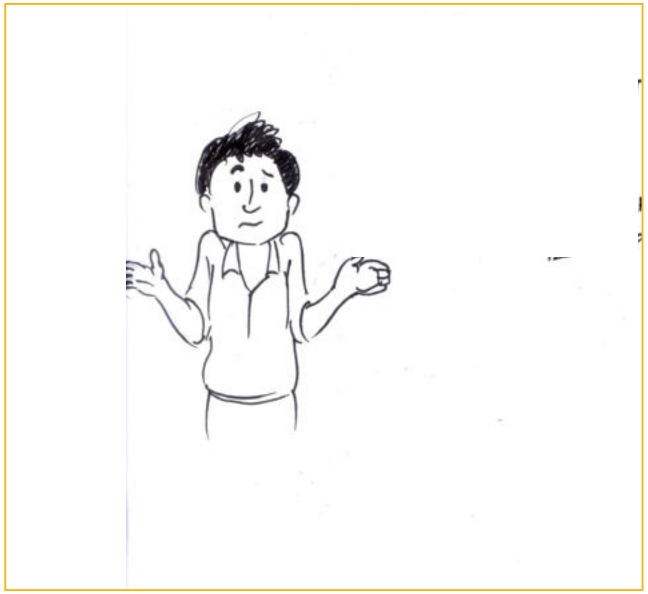


He is very excited seeing this as it looked like a game environment

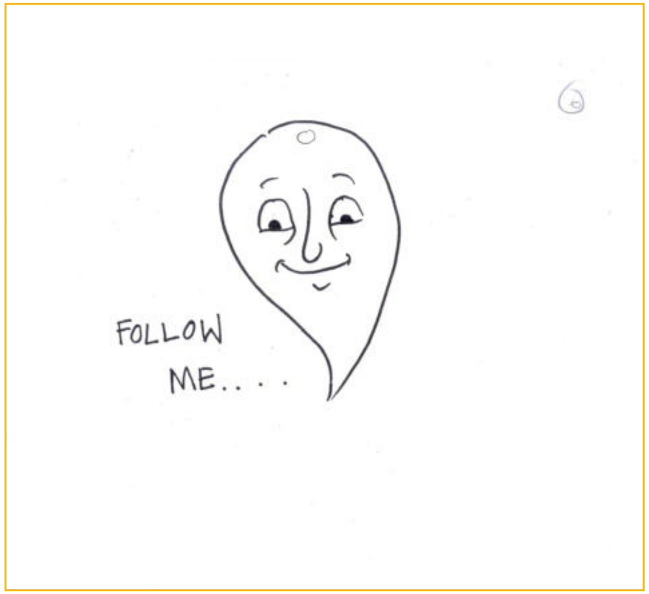
Rohan started touching the things around.



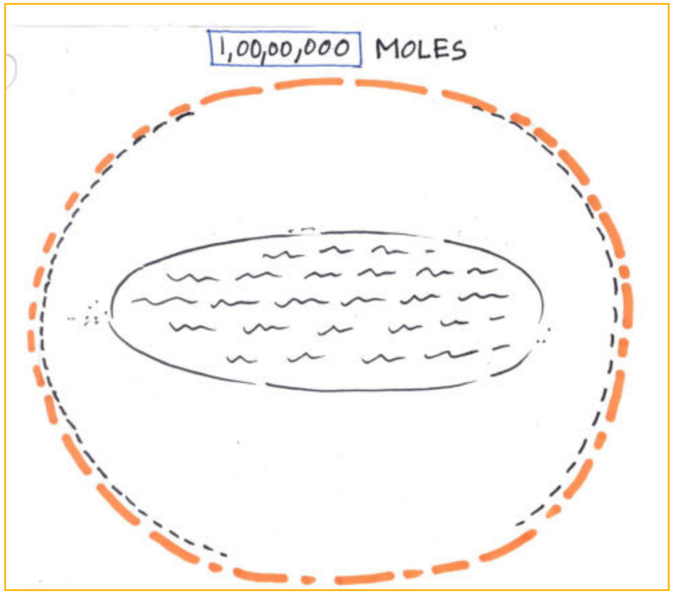
On touching the blob on the pond, to his surprise, a genie appeared and asked him a quiz, that too about mole.



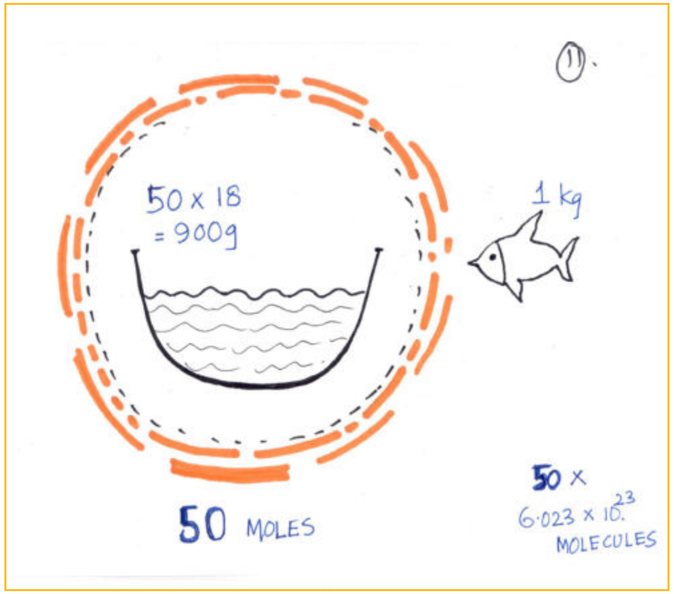
Rohan, as he is new to the concept of mole,couldn't guess how much it would be. He thought that it would amount to a hundred moles.



But the genie was happy to teach him and asked him to follow .

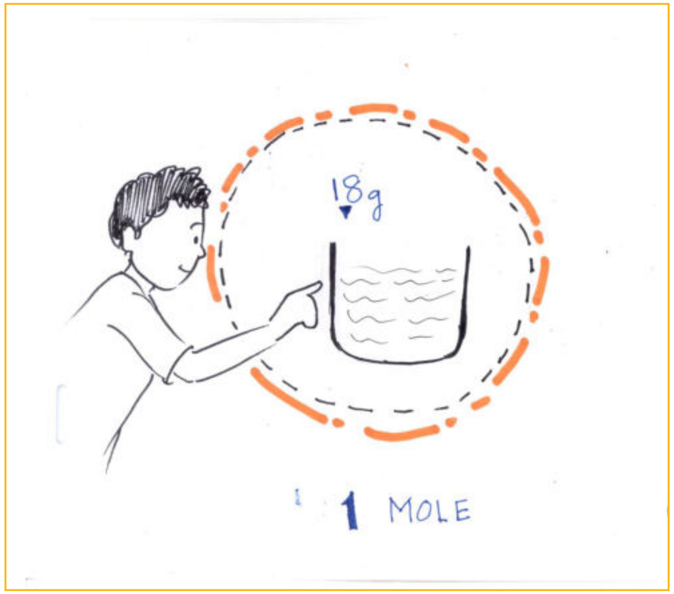


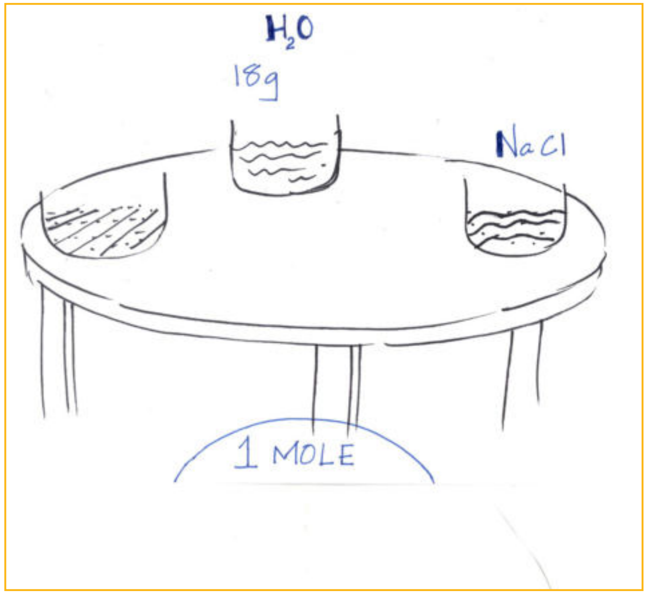
After this point, it was a magical journey for Rohan. He started flying into the depths of the pond and the genie whispered to him that it was a million moles and explained the reason.



Rohan further went deeper into the system exploring smaller amount of moles of water. Genie also showed him that he can compare the 50mole mass to a 1kg fish.

Rohan could also explore the the other substances around by touching it.

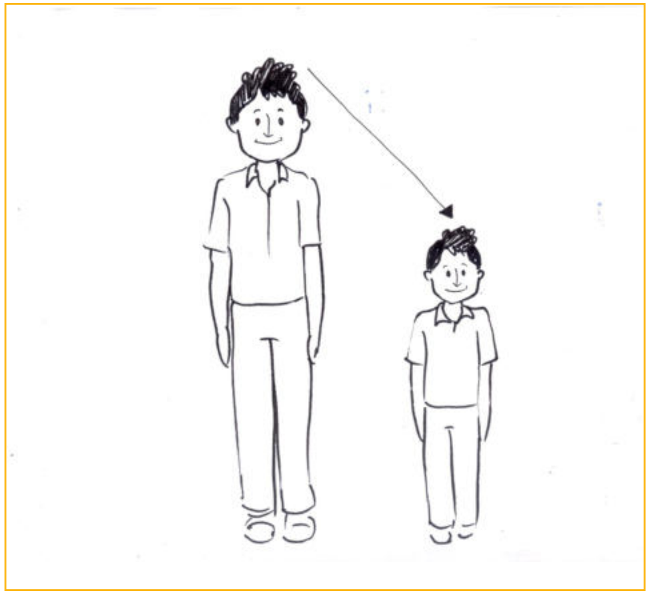


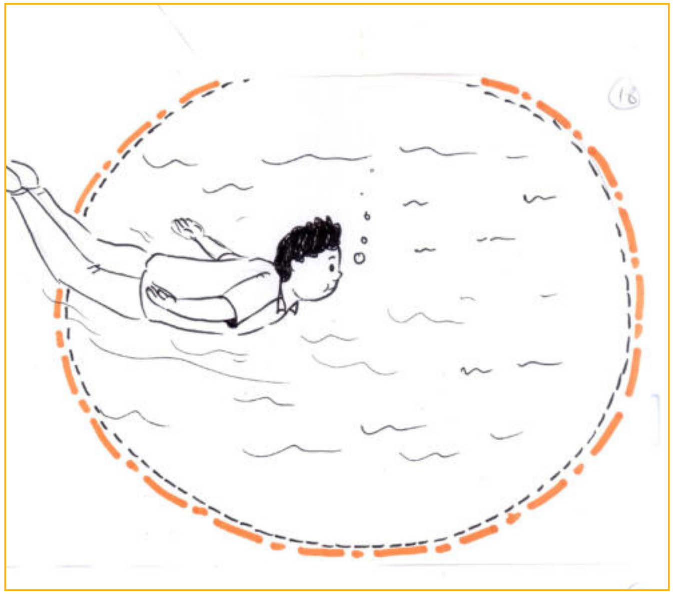


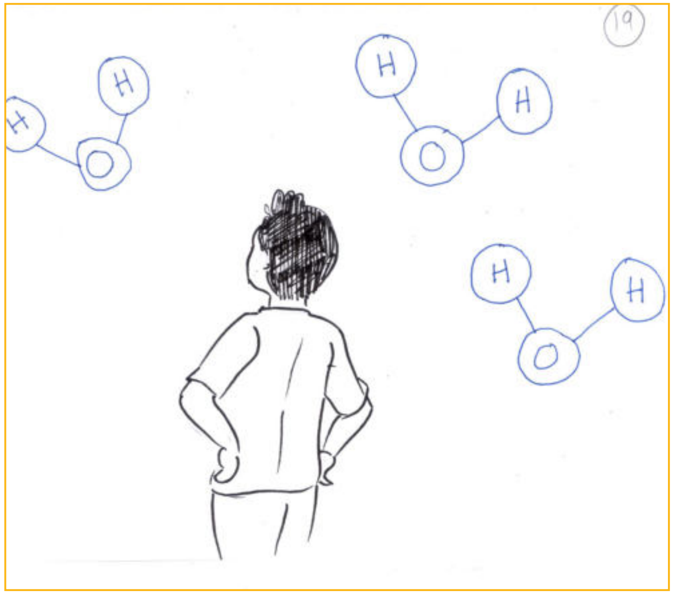
At 1 mole level, everything reached a standstill . He could see how 1 mole of water looked. On touching he could see that 1 mole of water amounts to 18g.

Rohan started looking around and exploring.

The table with water also contained containers of salt and phosphorous. He was able to compare the properties of these substances to each other.







After this point , the navigation started once again and rohan felt like he was becoming very small, when he went to the atomic level.

In the atomic level, he could see how a molecule of water is made and how so many number of molecules of water make one mole. Rohan further understood that he can reach back the fantasy environment by clicking on other elements or molecules in the atomic world.

This is the idea behind Mole scope

Wireframes

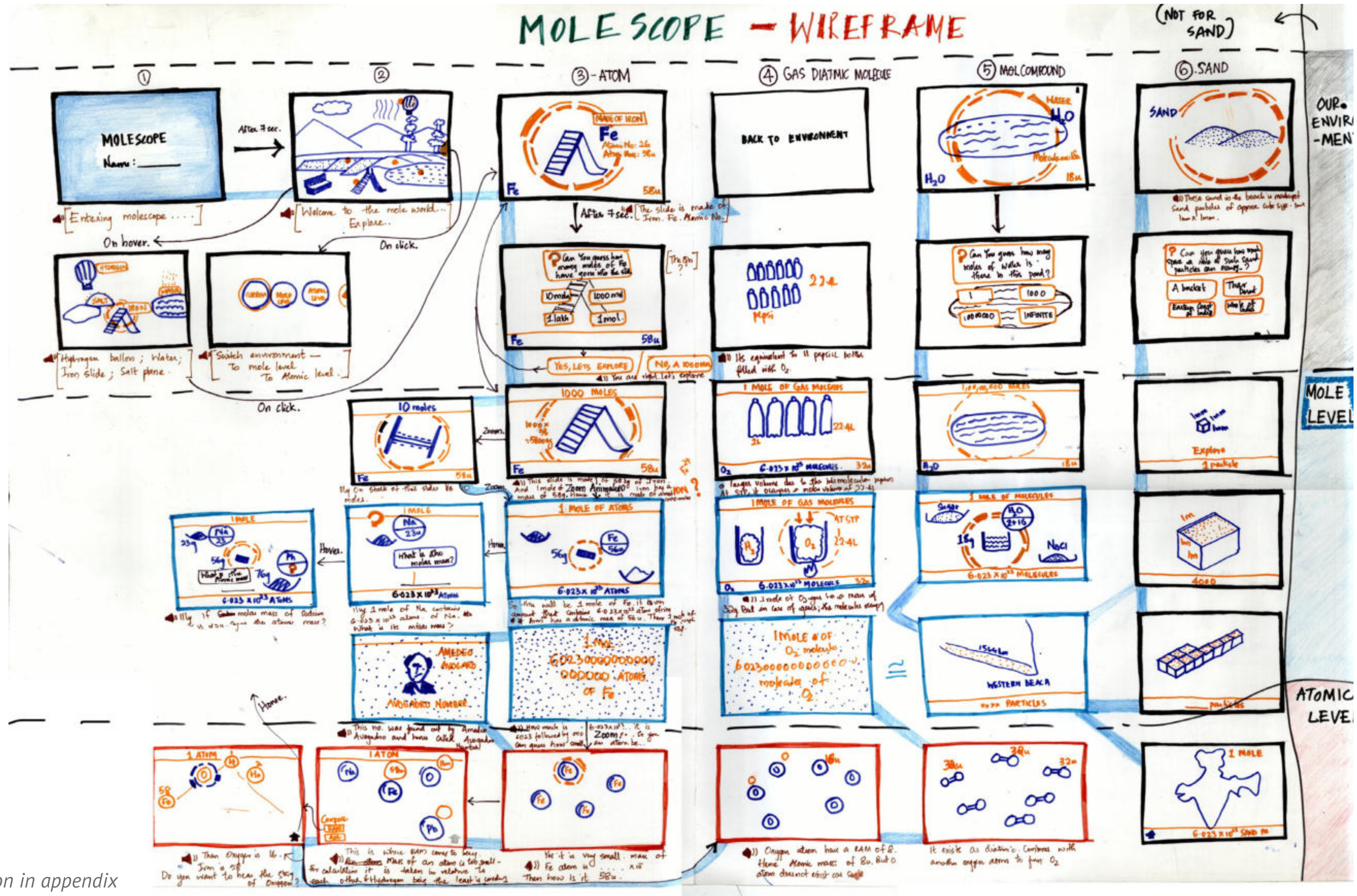


Fig.29 : Wireframes

Source : Author

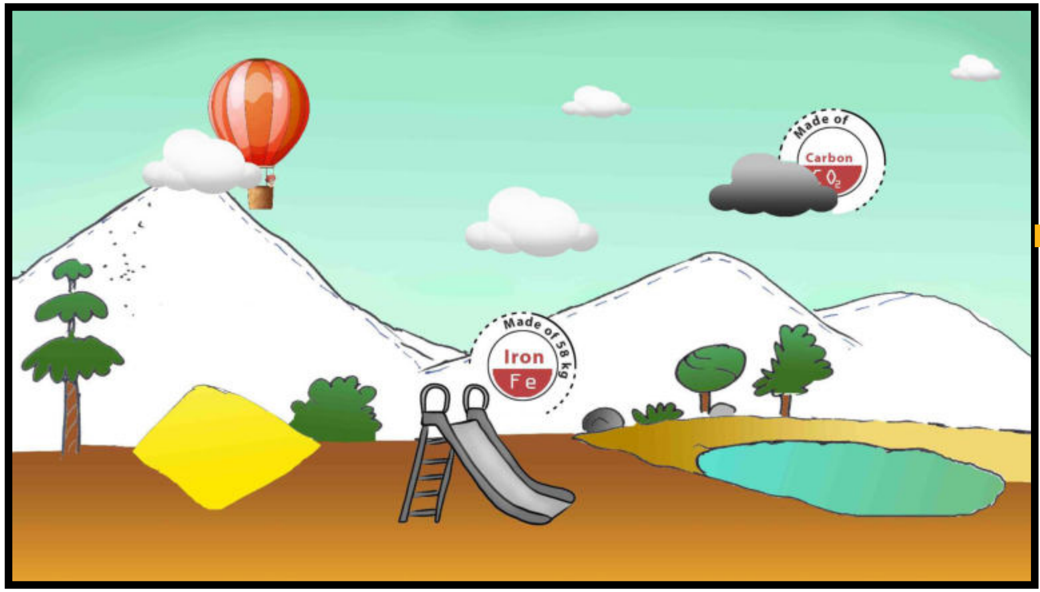
Bigger and detailed version in appendix

Design

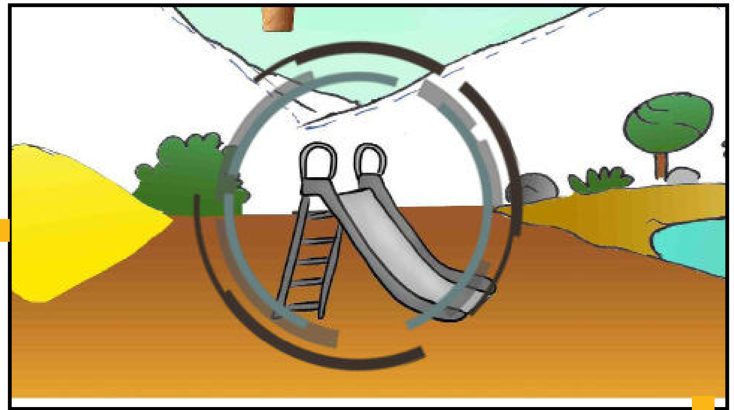
The wireframe explains the information flow for each substance.Two scenarios of the final design will be explained one the journey of Iron atom and the video made for sand grains. The prototype was made in Adobe flash and tested with students.

Starting Mole scope.

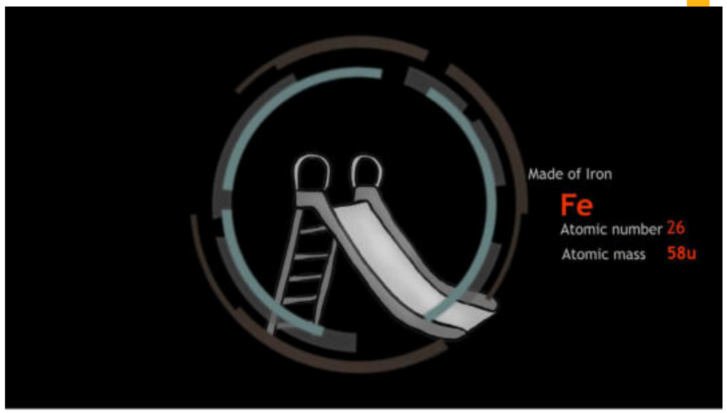
Fig.30 : Design and flow for Iron element
Source : Author



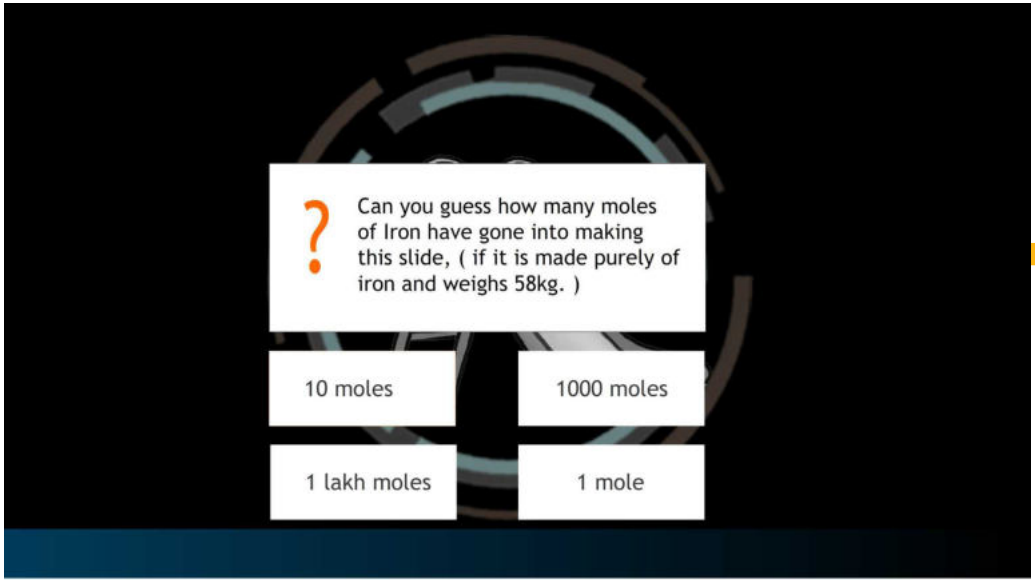
The student reaches the start screen which shows an environment with lake, mountains, play ground and trees. Children can explore this environment and see what each substance is composed of.



Once the Iron slide is selected, the screen zooms to it.

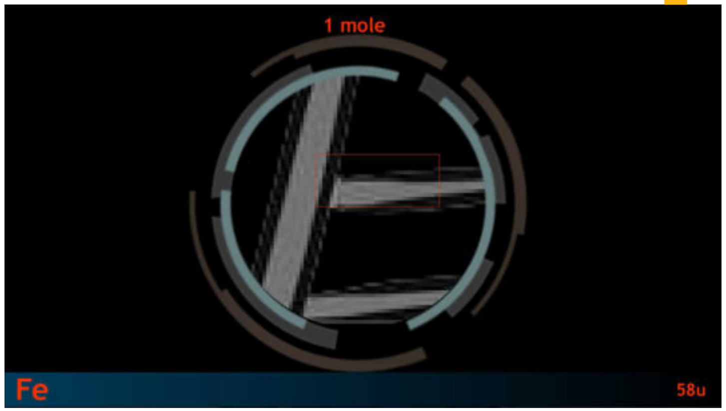


The specifications of the material is given to the students.

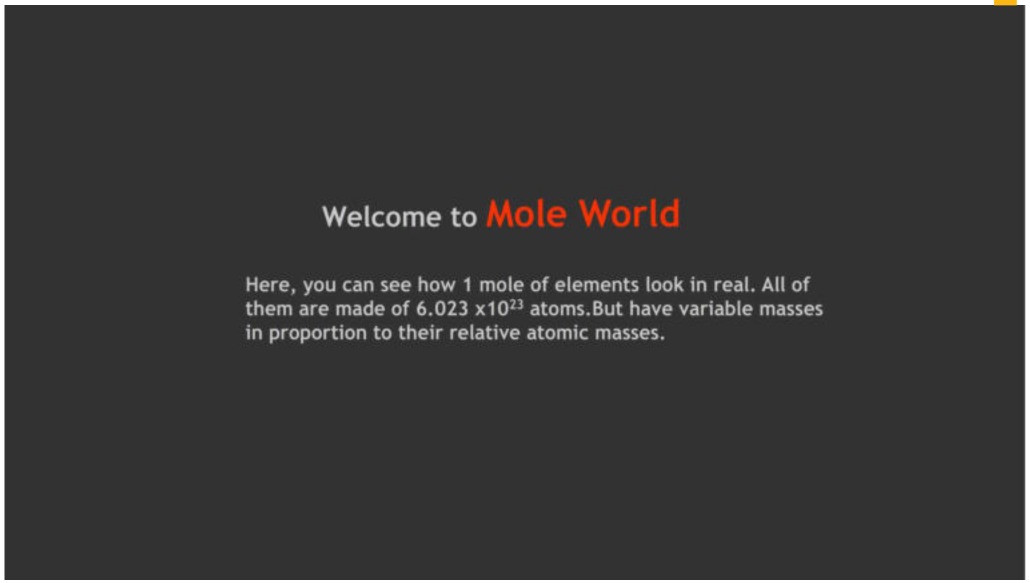


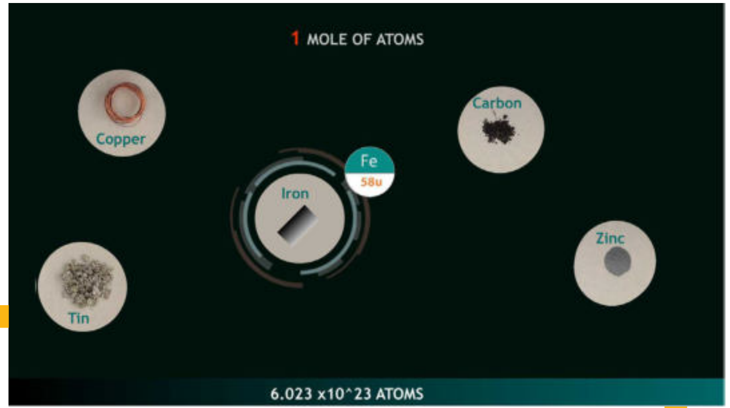
The students are given a quiz on the slide related to mole

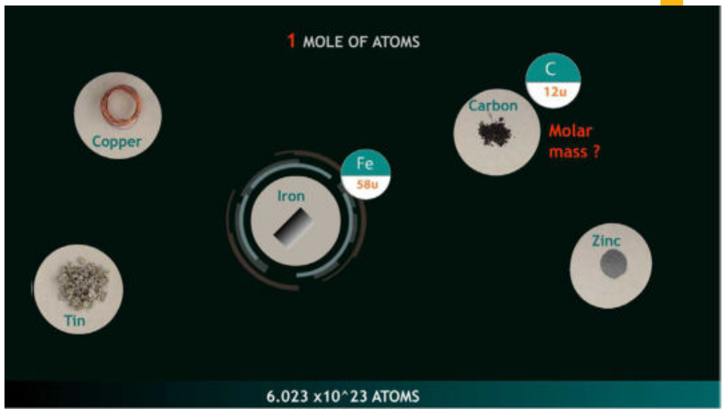
Further the answer is explained by the calculation

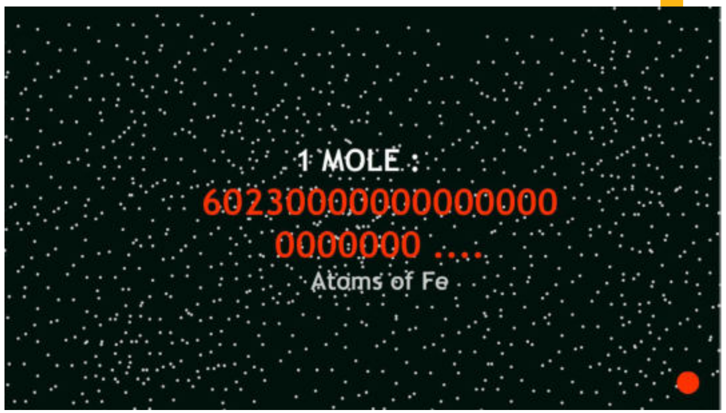


The animation zooms into the foot rail and a part of the foot rail is considered as 1 mole.









The mole world

How big is a mole?

While scenarios of other elements and compounds are similar to the one of Iron, sand is provided in the environment to show how big is a mole or how huge Avogadro number is. A mole of sand grains are considered instead of silica compound.

It starts with the assumption that consider sand is a cube of size 1mm x 1mmx 1mm. Then how much will be 1 cubic cm of sand and cubic m of sand. Still only a very small amount of sand grains are obtained . This scenario further goes to measuring the entire sand grains on beach to kms and filling whole of India with sand grains. The main intention is that the final result will surprise a student and helps him think how small will atoms be then.

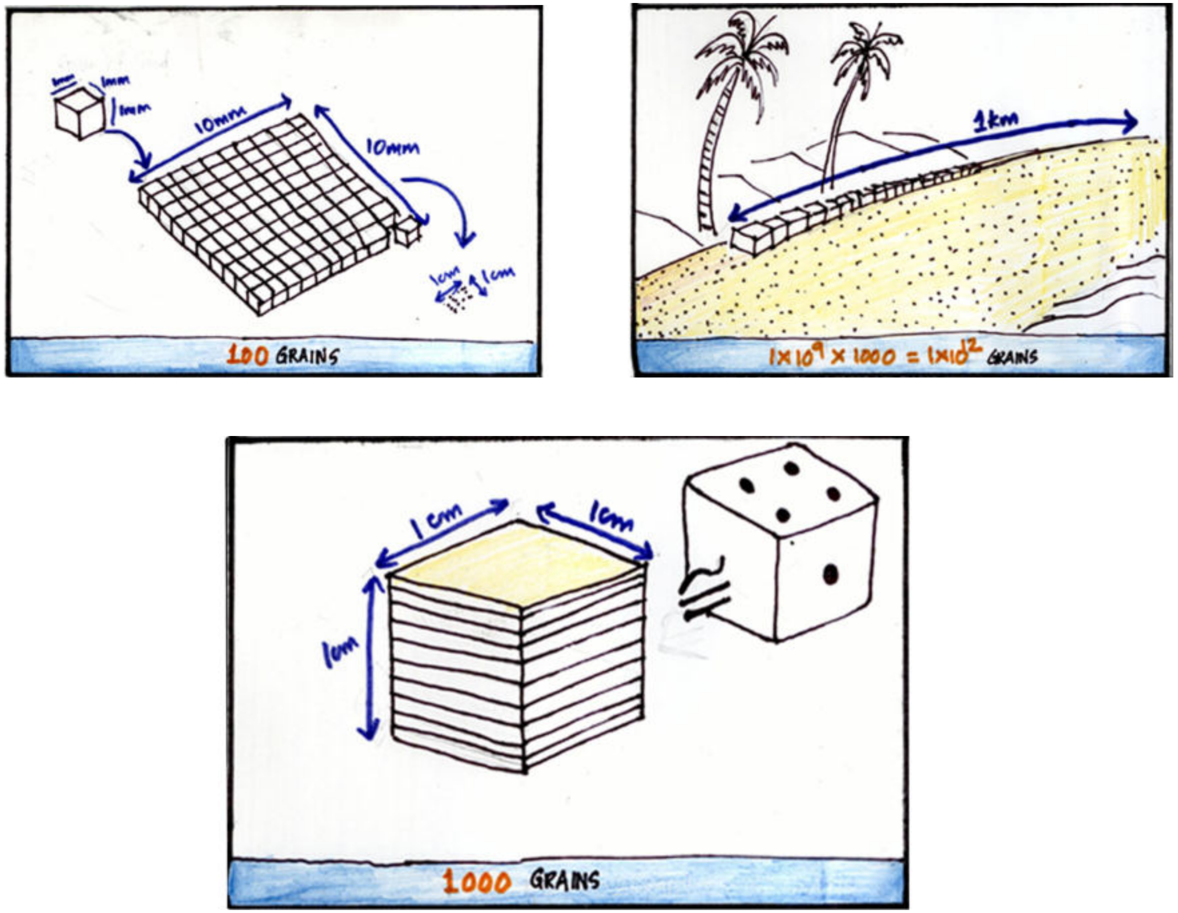


Fig.31: Video clip done for sand scenario
Source : Author

Testing and Feedback from users

Insights / Suggestions:

Teacher :

1. What are the chances of students relating to the-sand to atom comparison, due to the significant difference in their mass.

2. Teacher supported the idea of teaching mole through showing the bigness of Avogadro number as it is considered as one of the base principle in current new syllabus .

3. The product is not relevant if the child doesn't know anything about mole. The child should already be introduced to the concept.

4. There can be a confusion in the animation of sand as it is happening in reverse to rest of the substances.

5. Chances of mole of sand grains getting confused to mole of Silica.

6. Appreciated the usage of real objects to which students can relate to.

7. The slide made of pure iron might build misconception in children and Iron exist as Fe ions. This should be mentioned during visualization.

8. The product do not help the student in understanding or solving confusion arising during problem solving or stoichiometry in equations.

Student :

1. A Student did not like the exploratory nature of the prototype. Narrative should be given like in the sand video.

2. The starting of the application was rather confusing for the students . They didn't feel like they were going to learn chemistry after seeing the animations. 'how is it related to mole concept'?.

3. Students want to easily solve the tough problems. One student told it didn't have any connection with the problems asked in entrance exams.

4. 2/3 students were quite shocked seeing the sand mole statistics and they expressed they will never forget it and were quite embarrassed about their pretest answers.

5. Students were of the opinion that both videos looked interesting and were not boring.

Fig 32 : User testing molescope : reactions

Rethinking project

As learning through one exploration activity

- Molescope didn't help students get the gist of mole and didnot explain why mole is taught and its application in stoichiometry. This was identified as because of the lack of systematic approach covering all prerequisites of mole. Problem solving cannot be totally ignored as that is what the current curriculum demands. Hence I decided to go back to the ideal scenarios made for each hardspots and come up with similar activities that students can do in levels of problem solving.

The scenarios explained are very linear and focused on all topics. To make thinks interesting, a platform that helps students to discover themselves should be designed. The major focus is given to an activity. This is interactive tool based on visualization of atomic entities. Time to time students are feeded with the linear scenario activities.

Breaking the misconceptions about mole is the main agenda, and hence, feedbacks are given at student actions that accept or contradict their beliefs.

Concept 2 mole gyan

Product

A stand alone interactive tool that aids students in learning mole concept through activities and lessons. The objective is to

- Reduce misconceptions
- Practice and learn the basics

User

Students from 9th and 10th standard

Contexts of Usage

1. Students can access it from the internet at home or school and self learn.

2. The tool comes along with the teaching manual as activities students can try and teacher suggests the link to them.

Final Concept

The concept is to give the major focus of the tool on activities which is made up of 4 levels based on the difficulty of principles and flow of the concept. The final level will be a test game that is both interesting and examines the students knowledge.

Each level has its own learning objectives, but the main focus is on breaking the misconceptions, if any in the students. The conceptual model and levels will be explained in detail in the next section.

Conceptual Model

The major component is the 5 levels of the tool each comprising of mainly activities and supporting lessons.

Student needs to login before entering the levels. After a student login for the first time, he has to go through each level step by step. He can't skip levels or start at a higher level as the first levels are prerequisites of the subsequent levels. In each level, if he finishes the activity without making mistakes, he can reach the next level directly. Else, he can go through the video lessons provided and then complete the activity. Once all the activities are done and he is back in the home page, a report is generated as feedback to rate his knowledge.

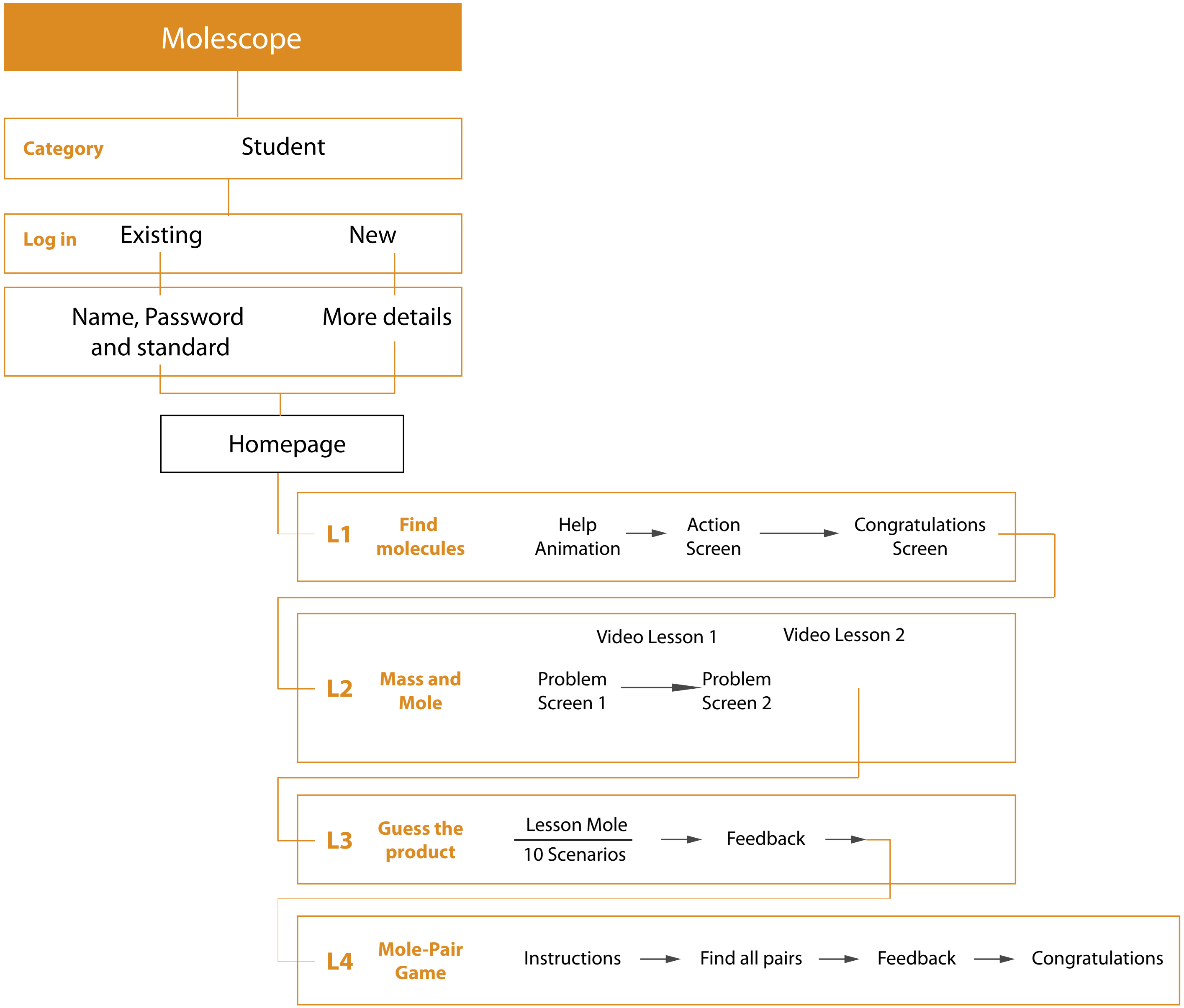


Fig 33 : Conceptual model

Levels of Molegyan

Level 1 - Find molecules

Learning Objective

1. Students should be able to identify that elements are of different type - mono atomic, diatomic and poly atomic elements.

2. Students should be able to deduce that atoms are not all the same and atoms of different elements are of different masses and configuration.

Strategy

Components : This level comprises of only one activity with feedback as hints. Help lessons are not provided due to the simple nature of the activity.

The first stage is a warm up activity for the students to make molecules of the elements and compounds from the given atoms. This activity is a base to teach that mole is not only for molecules, but for atoms, molecules of elements, molecules of compounds and further any substance. This also gives an introduction to correct the issues regarding language ambiguity and confusion between mole of atoms and mole of molecules of poly atomic elements..

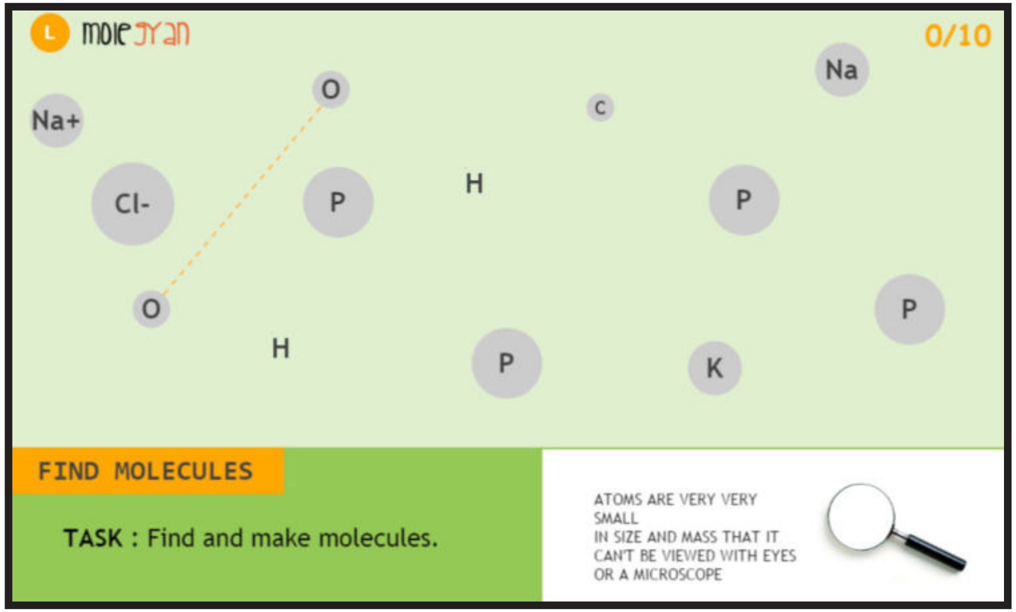


Fig.34: Level 1 - Make the molecules
The user have to make meaningful molecules out of them.

Level 2 - Mass, Number and Mole

Learning Objectives - Activity 1

1. Students should be able to calculate molecular mass of elements from atomic masses and vise versa.

2. Student should be able to visualize what is relative atomic mass of elements.

Learning Objectives - Activity 2

1. Students should be able to calculate molar masses

2. Students should know that molar mass is a certain mass /mole or g/mol

3. Students should be able to differentiate between mole of atoms and mole of molecules

Lessons

Video lesson1 : What is relative atomic mass?

Video lesson 2 : How big is mole?

Strategy

This level comprises of 2 activity and 2 lessons. The activity is a simple form of quiz were students have to find atomic masses and molecular masses of same elements.

Level 3 - Guess the product

This is were the use of mole in stoichiometry is introduced.

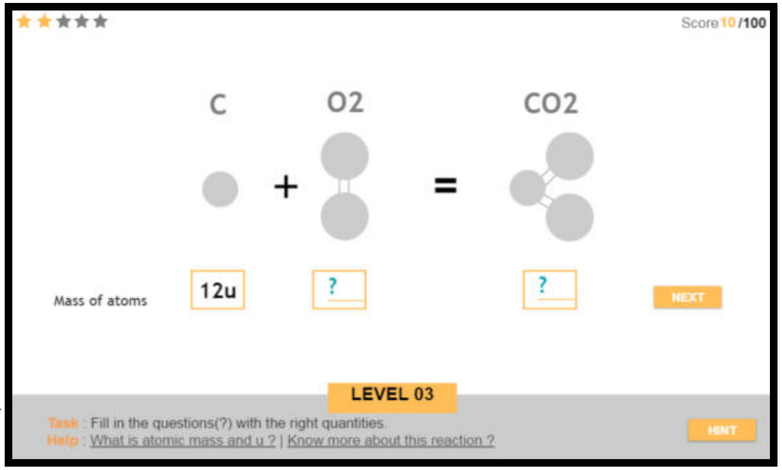
Learning Objectives

1. Students should be able to predict the quantity of reactants or products from those given in the equation.

2. Students should understand that reactants should interact in particular proportion to get the product completely. Otherwise, a reactant becomes limiting reactant.

Strategy

This level comprises of an activity and 2 lessons. As the major use of mole is in stoichiometry, this level uses equations to build idea and break misconceptions. The activity prompts ten relevant coefficient questions on the Carbon combustion reaction. The quantity of the reactants and products are visualized in real time as the student is entering the data. Students enter the coefficients by selecting from a small list of numbers.



Level 3 - Initial wireframe : Predict products on Carbon combustion reaction - Mass of atoms

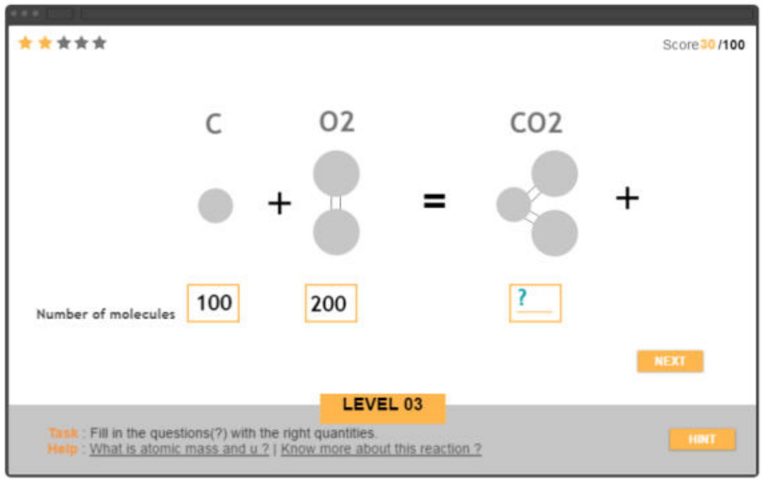


Fig. 35 : Level 3 - Initial wireframe : Predict products on Carbon combustion reaction - Molecules

Level 4 - Mole pair game

Testing Objectives

1. Problem solving ability- Convert between various quantities : Mass and mole, Volume and Mole, number of particles and mole.

2. Testing whether they have come out of the misconceptions listed and understood mole.

Strategy

This is a board game with 4x4 tiles having pairs of tiles with substances with same amount(no. of particles) or same mole. The atomic masses of the components are given behind the tiles(physical game) or on hover(digital).The task is to identify pairs of tiles that correspond to the same amount.

Once each pair is found out, the game shows the respective visualization of moles and the students can compare the amount.

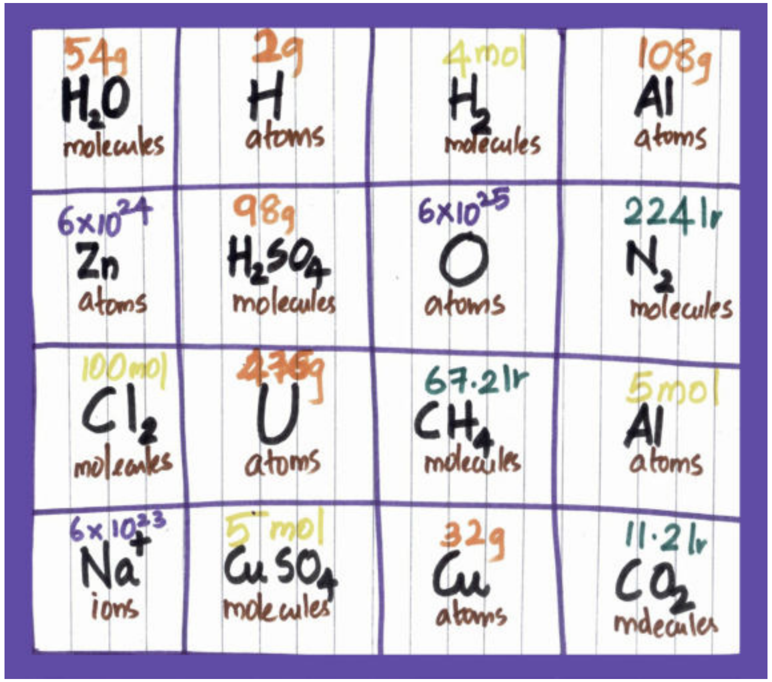
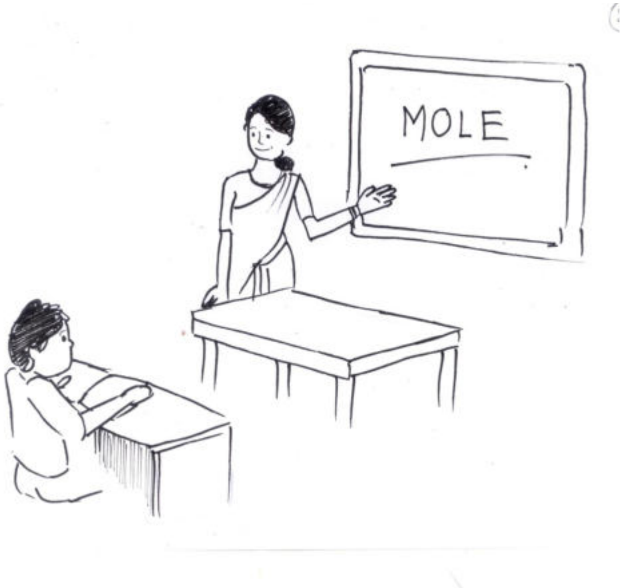


Fig.36: The mole pair game

Final Design

Finding Molegyan



Figures 37 : Solution scenario molegyan

Rohan is a fun loving 9th standard student from KV School , Powai

This week, Rohans chemistry teacher taught a new topic named as 'mole'. This topic comprised of atoms, molecules, Avogadro number and many problems.

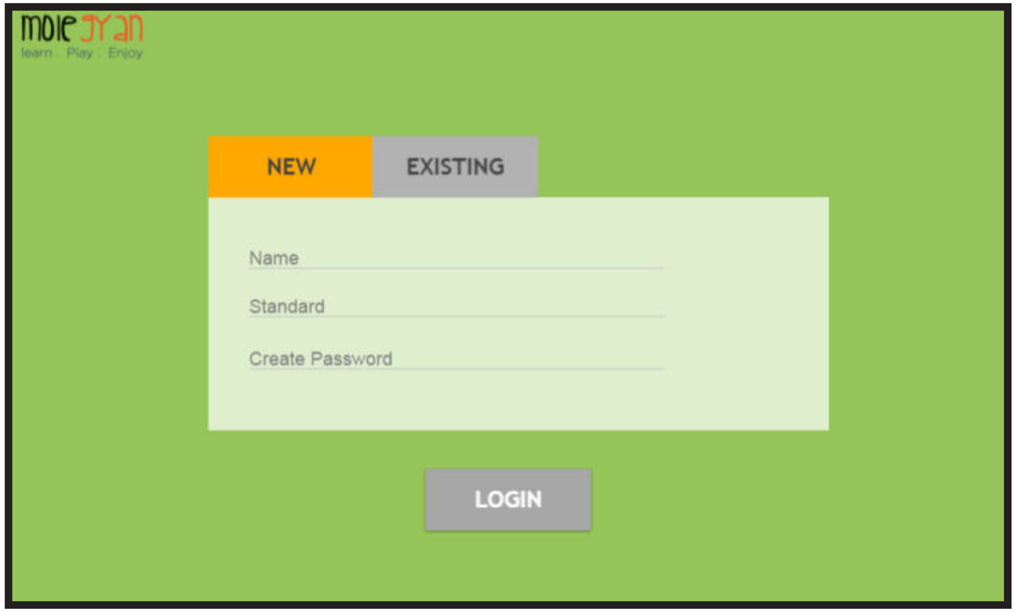
But, He did not understand the concept and didnot know to do the problems on mole conversions. He was worried about the home works given.

So, he decides to search internet for materials or activities through which he can learn mole. That is how he discovers Molegyan.

Using Molegyan

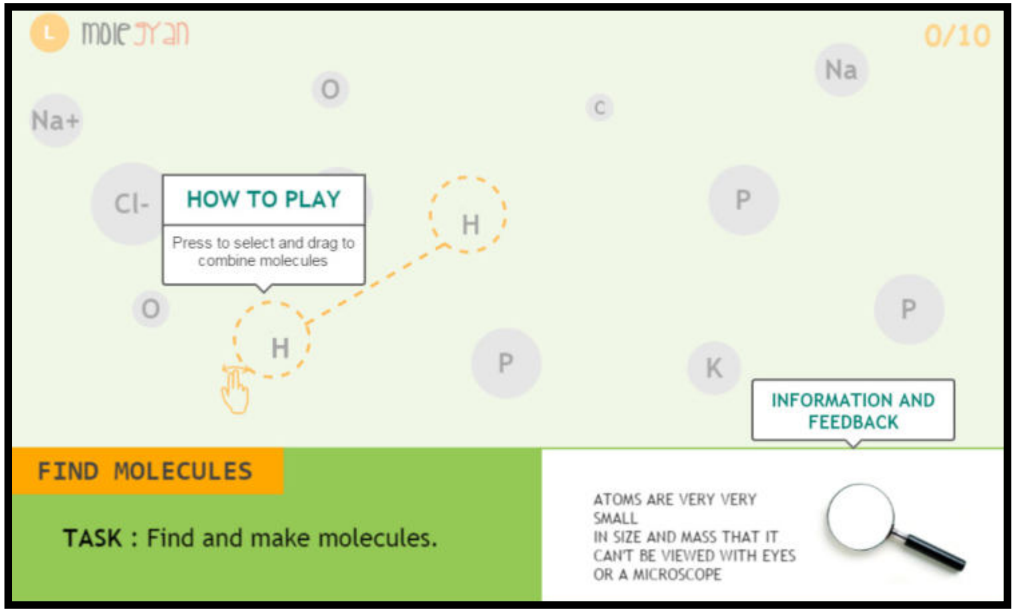
He sees the starting page which gives him a feeling that the application might be fun. This page stays for 5 seconds.

Login



This takes Rohan to the login page of students. As he is new to the application, he fills in his name.

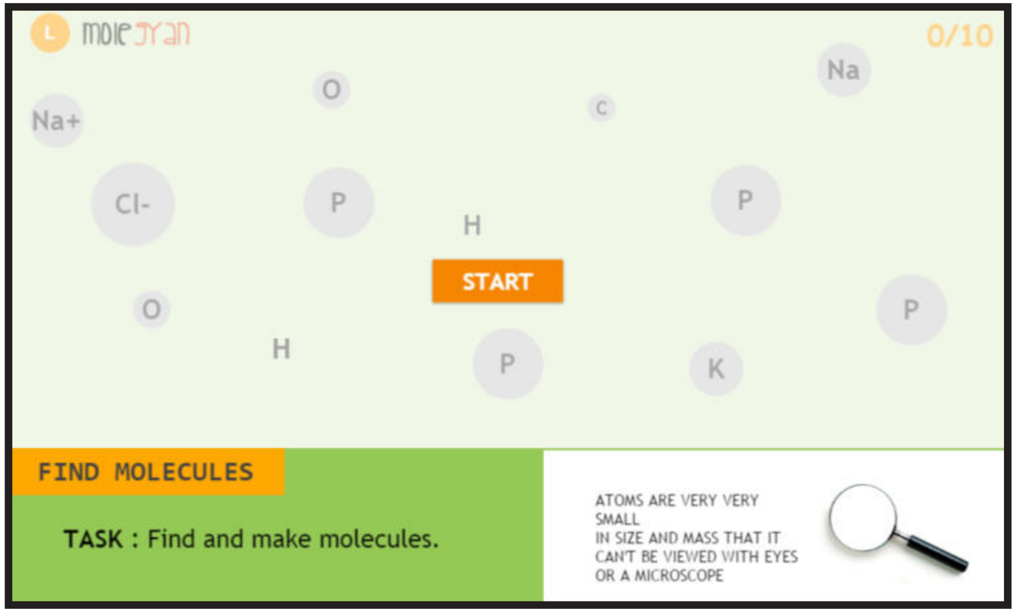
Selects 9th standard as his class and creates a new password.



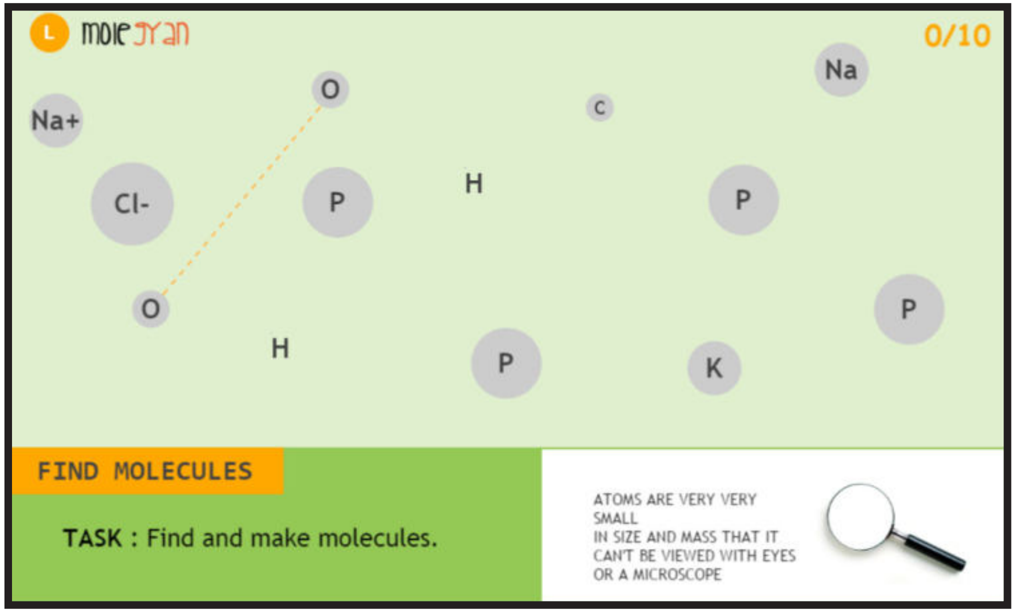
Home page : Rohan sees that the application has various levels and the first level - Find the molecules is highlighted. He decided to checkout the initial level.

Rohan understand that he has to 'find and make molecules' and in order to do that he has to press and drag individual atoms. Feedback will be provided in the box at the bottom right.

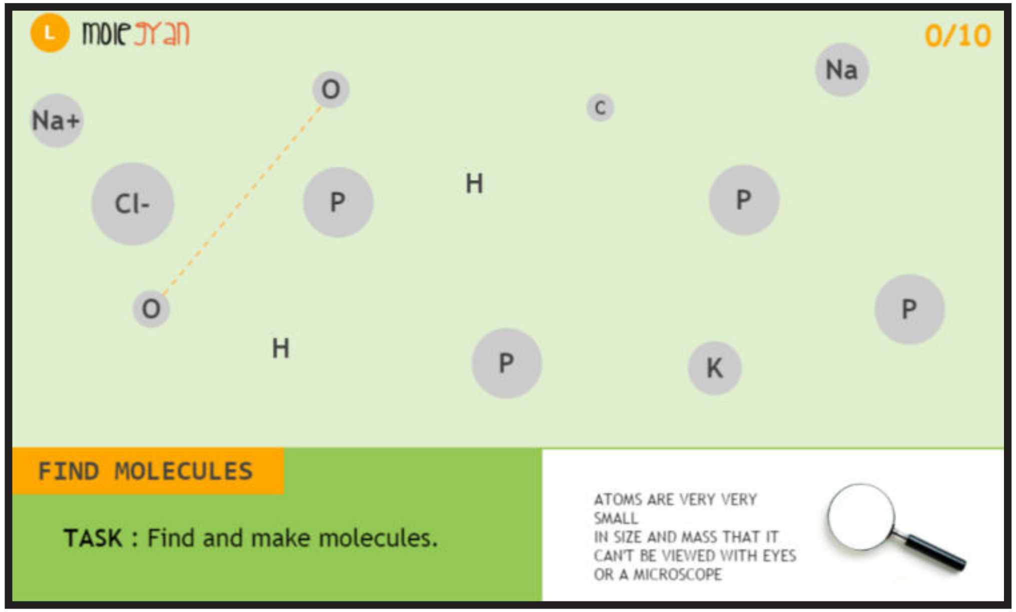
Level 1 : Find molecules



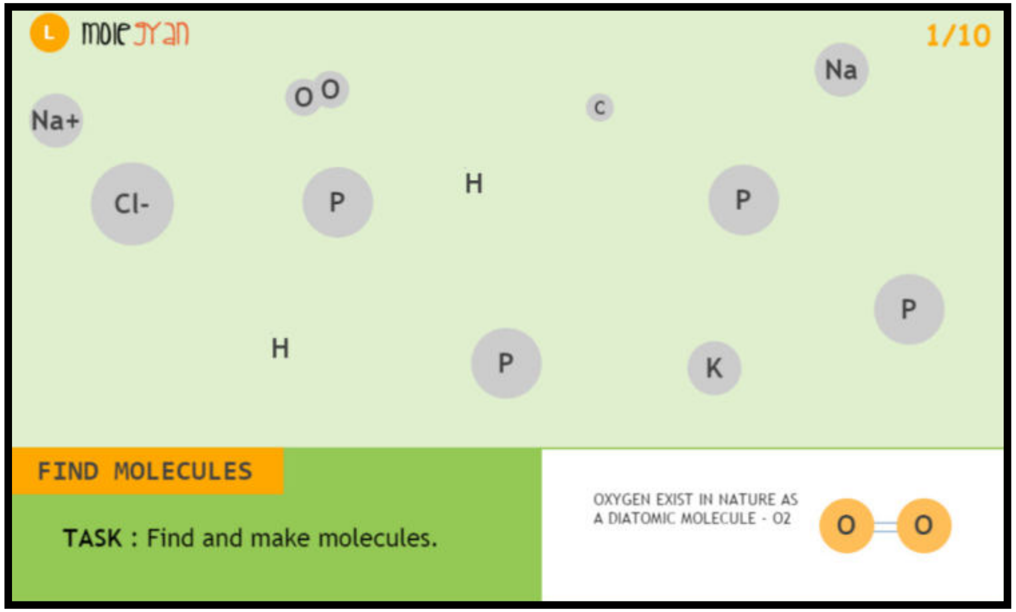
After he read the instructions, he clicks on the screen for further actions and a start button appears. Rohan clicks on the start button to initiate the level.



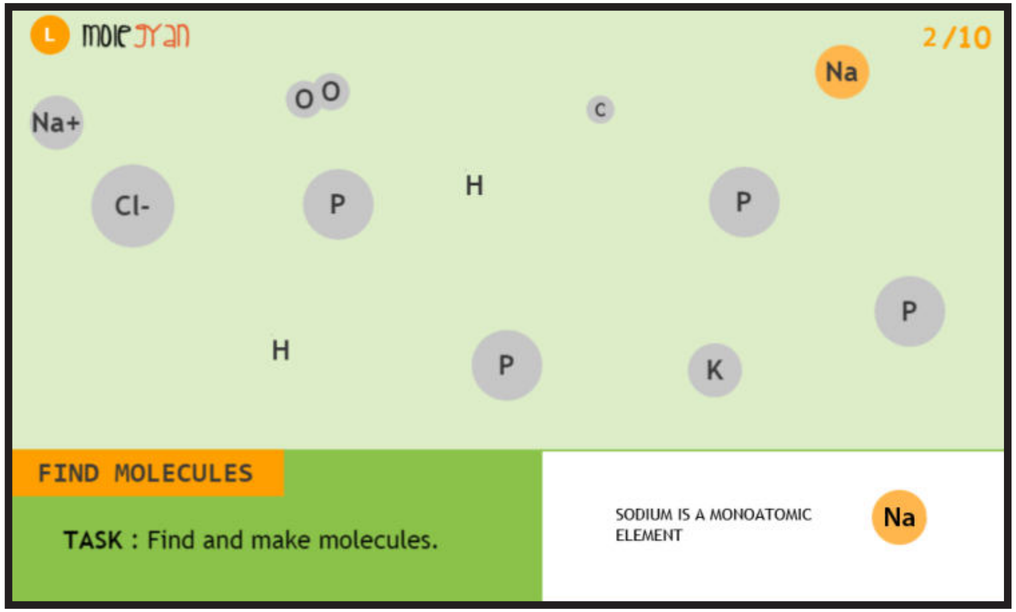
Once in the level - Find molecules, Rohan sees individual atoms and ions in the screen corresponding to their sizes. Hydrogen atom is the smallest and chlorine ion is largest. He understands that 'atoms are very small' from the instruction.

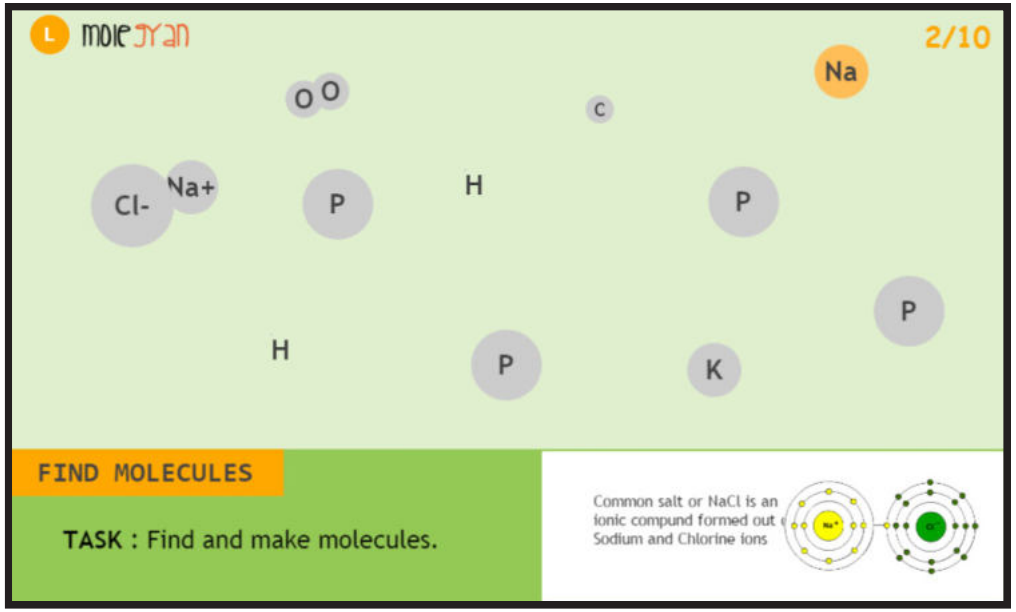


Following the earlier instruction given, Rohan clicks on the oxygen atom. A line appears connecting it to the other oxygen atom. Rohan drags one atom on top of other to see what happens.



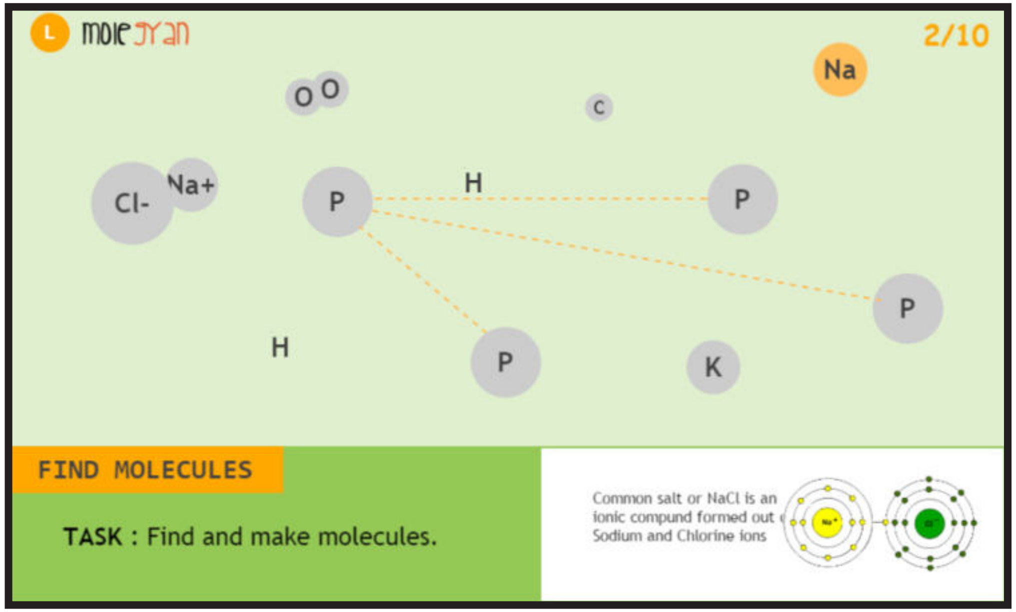
Rohan sees that Oxygen molecule is found as there is a 'sound feedback ' associated with a change in the point to 1/10. He also understands that oxygen is a diatomic molecule with the shown atomic model from the feedback column.

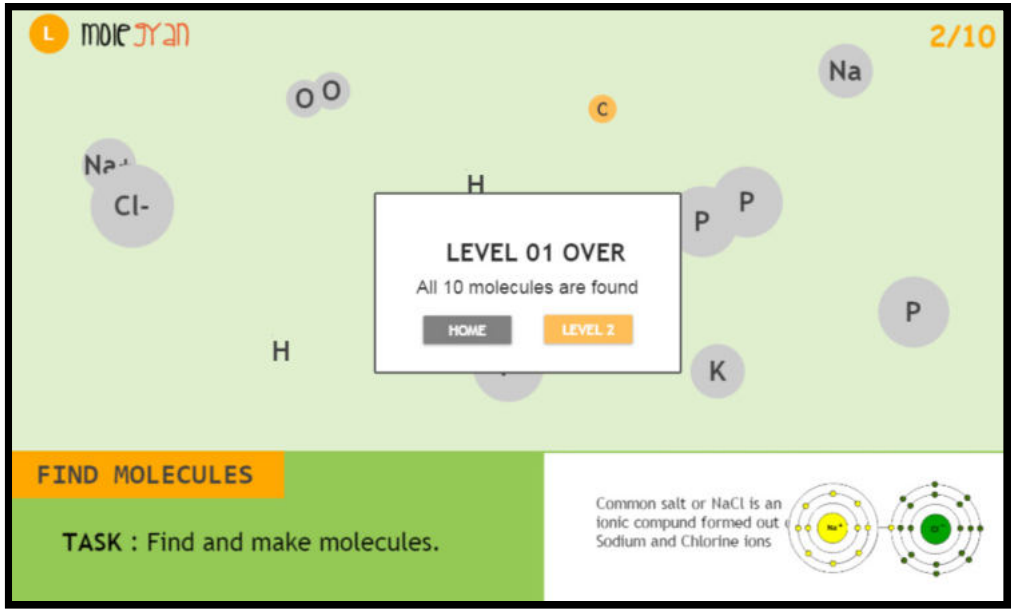




Rohan already knows that Sodium (Na) is a mono atomic molecule. So he presses on it to get similar voice and text feedback.

Similarly it happens for NaCl. Rohan recollects his learning that NaCl is an ionic compound.

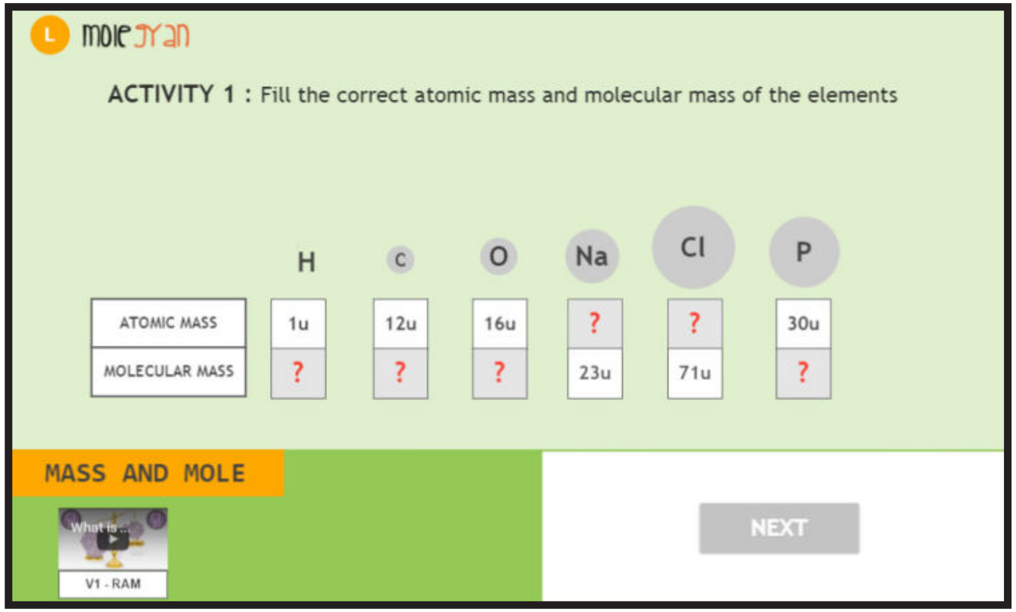


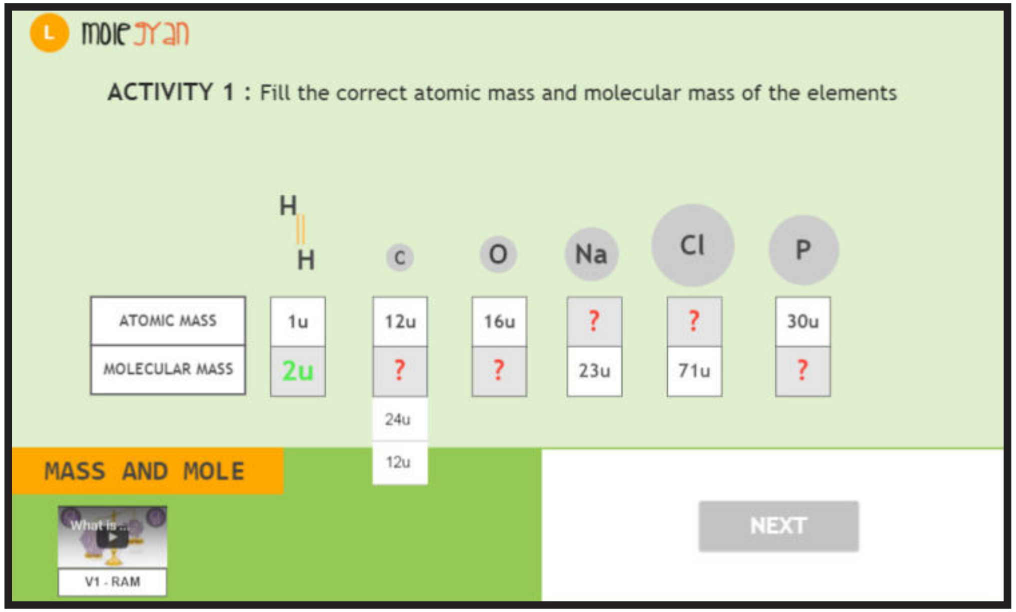


Once he is clear with the actions, Rohan knows how to find other molecules. For example the tetra atomic molecule P4.
Other scenarios : What if Rohan is confused even after giving the hint and decide to quit?
What if Rohan is too brilliant and finds all molecules in 5-10 seconds?

Once all the molecules are found, It proceeds to the next level.
<sound:level accomplished>
Further design: Summarization of feedback for students to retain the purpose of the activity. For example, the molecules found with their

Level 2: Mass and mole - Activity 1





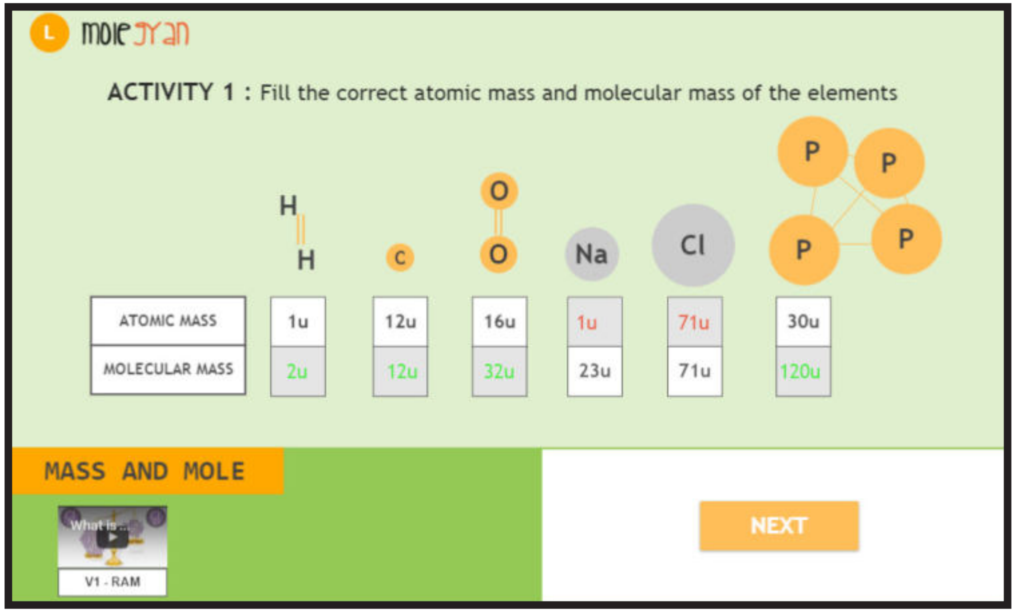
Level 2 is called mass and mole and it starts with an activity to find the molecular masses of the given elements from the atomic masses and vice versa.

From the takeaway from previous level, Rohan already knows which are the mono atomic and diatomic elements which helps him to fill the answer from the list.

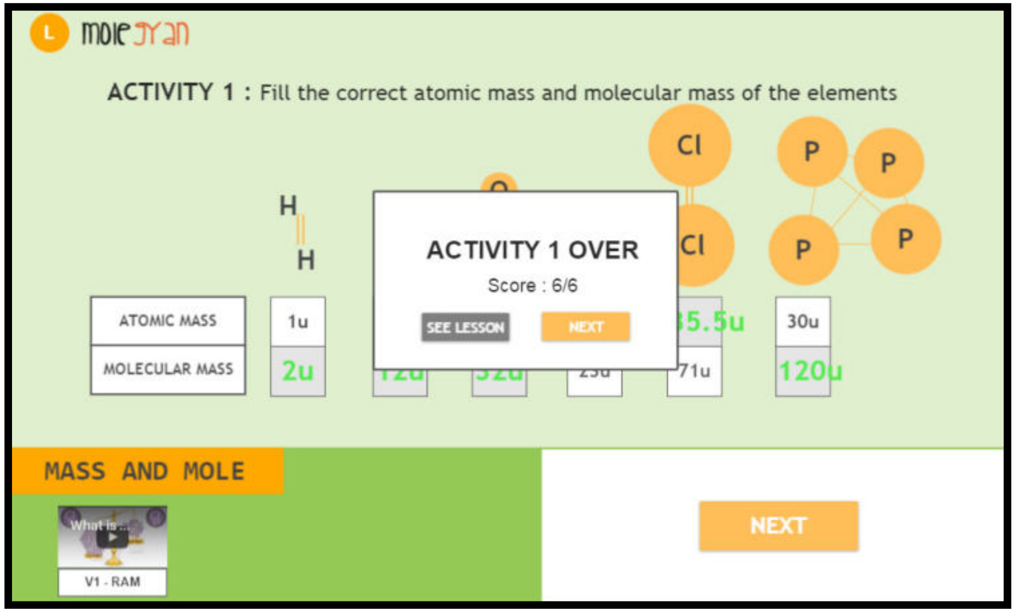
This activity is quite self explanatory as Rohan has to fill in the question marks still he gets the right answer(green). Once he enters the right answer for Hydrogen he decides to try carbon. The list contains two options. And the right answer, 12 u gives an auditory and visual feedback.

Other scenarios : What if Rohan forgot the atomicity of any of the element and wants to refer to the summary in Level 1?

Scoring in the level for multiple mistakes ?

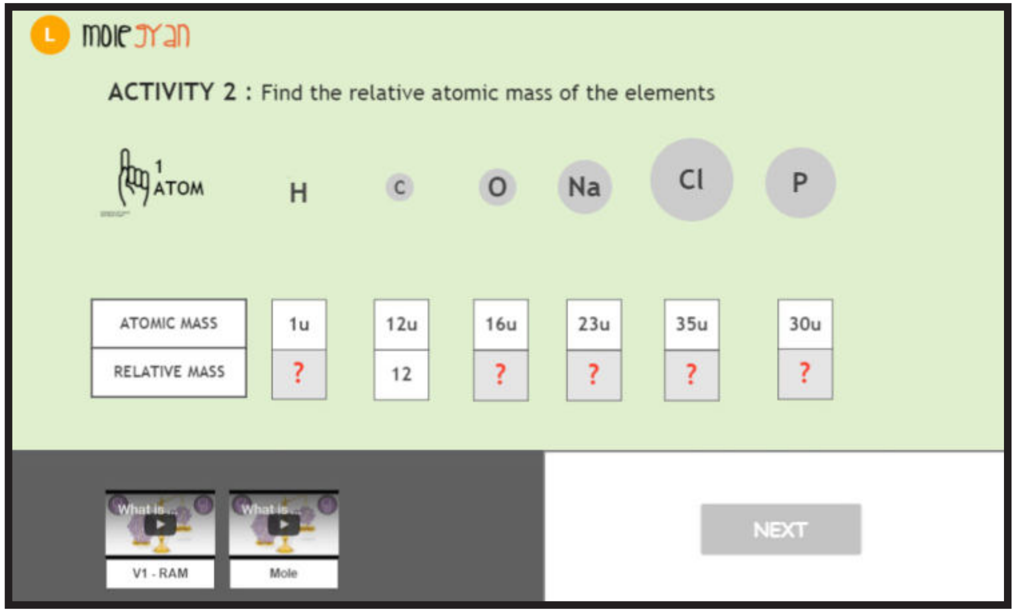


Similarly Rohan selects the right answers of other elements.

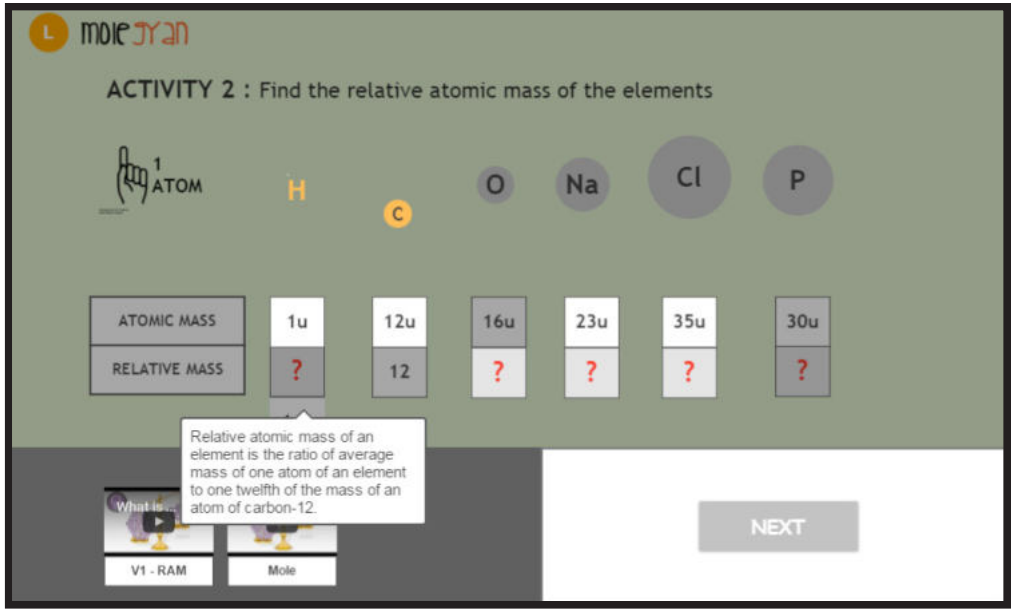


If Rohan gets a very low scoring in this activity, he is prompted to see the lesson in the lessons tab. As Rohan has a good score, he can proceed to the next activity.

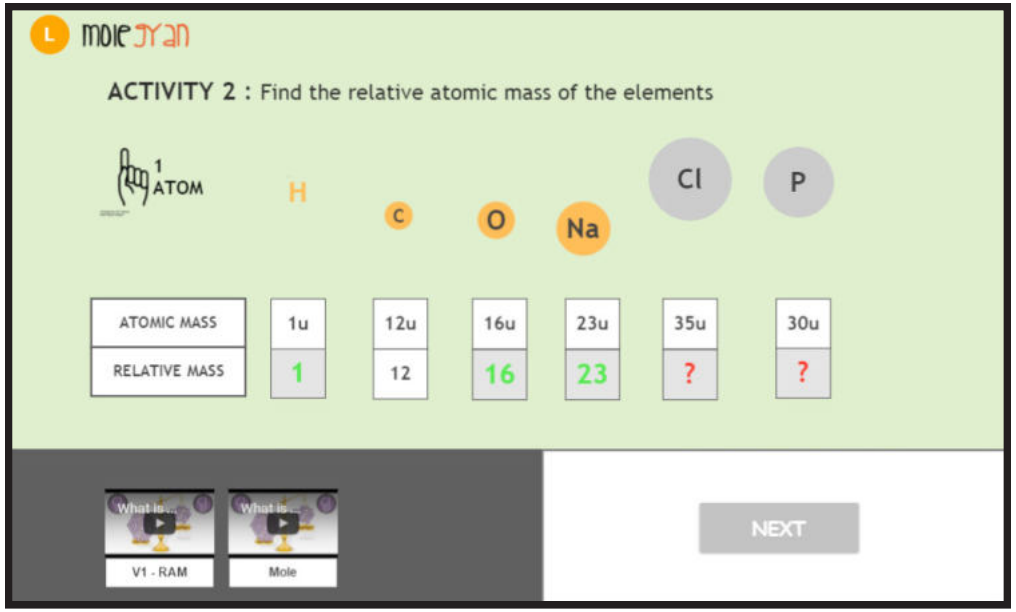
Level 2: Mass and mole - Activity 2



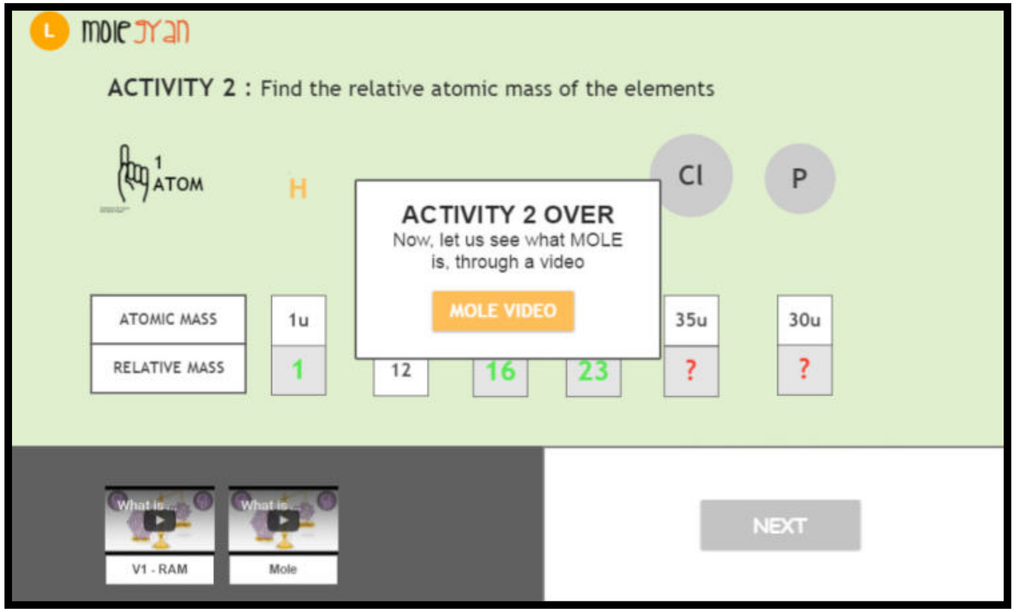
Rohan sees that the task in activity 2 is to find relative atomic mass. He didnot know what RAM is and hence he sees the new lesson that has come in the lessons tab and then comes back to the activity.



He attempts the RAM of Hydrogen; A hint about what Relaive atomic mass is and how it is relative to carbon. He selects the right answer for Hydrogen as 1. When he selects the wrong answer for Oxygen, the relative visual feedback will be absent and Rohan knows that the answer is wrong.



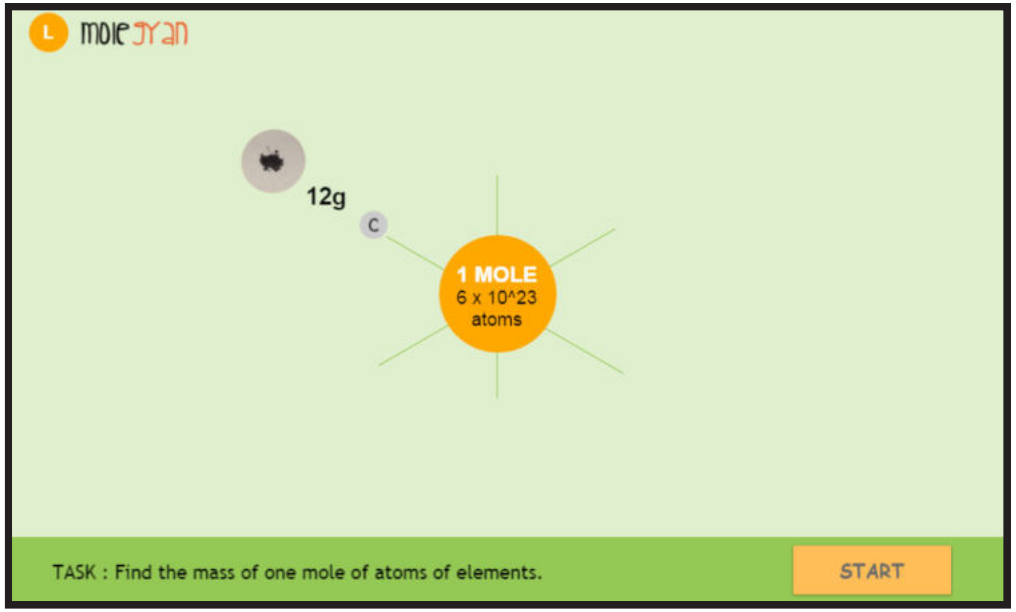
Similarly Rohan selects the right answers of other elements.



Once Rohan finishes activity 2 , he is prompted to see a compulsory mole video.

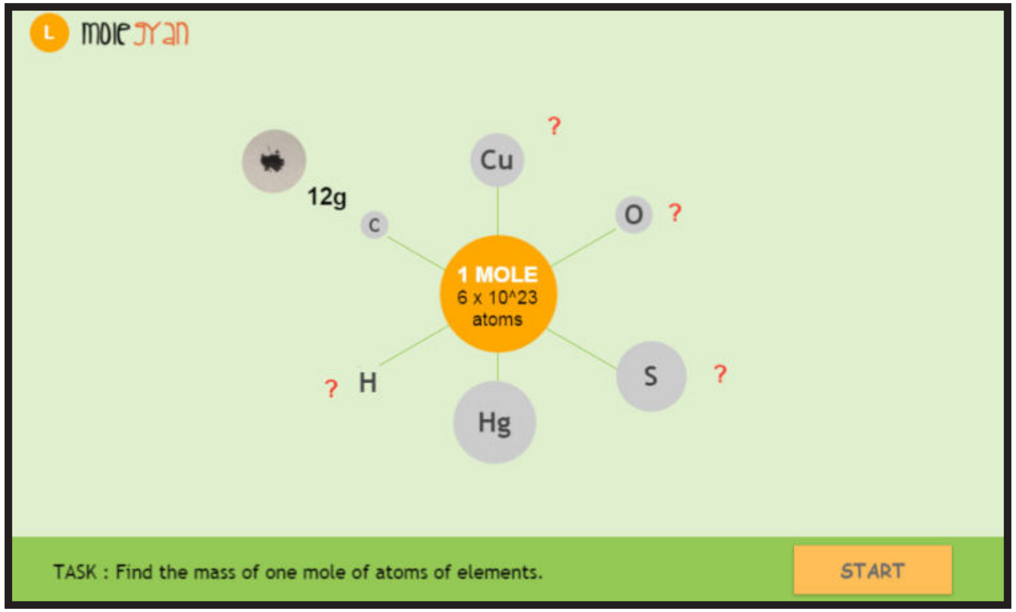
(This feature is added in the iteration as students find difficulty in recollecting what mole was).

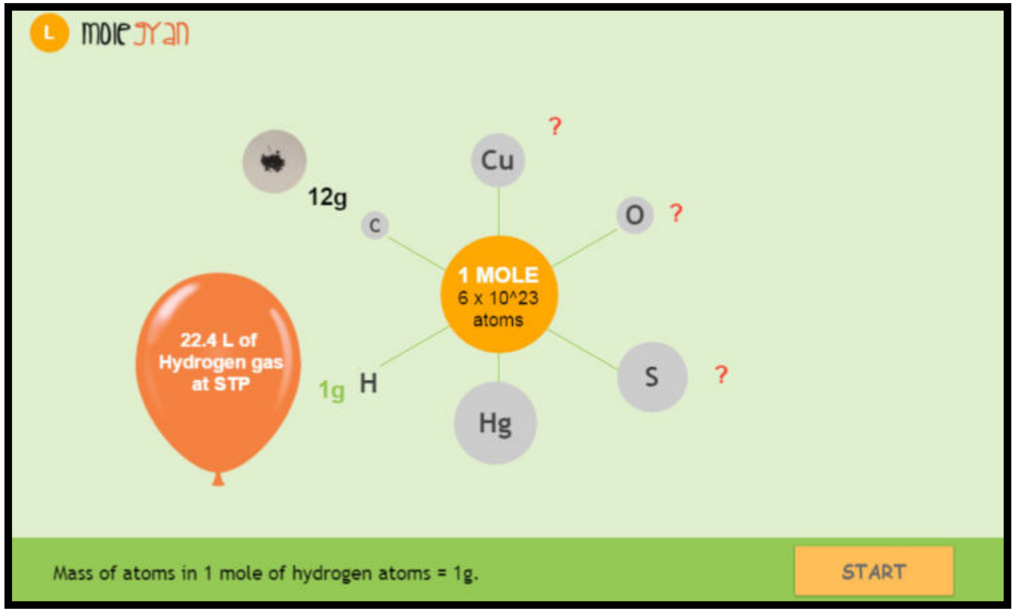
Level 2: Mole video



A 3 minute simple teaching video is made for students to recall the mole concept taught.

Once the entire video is seen it goes to the next activity solely about mole. This screen tells through an audio that 1 mole of Carbon weighs 12g and is this much, then how much is 1 mole of other elements weigh?
Rohan clicks start.

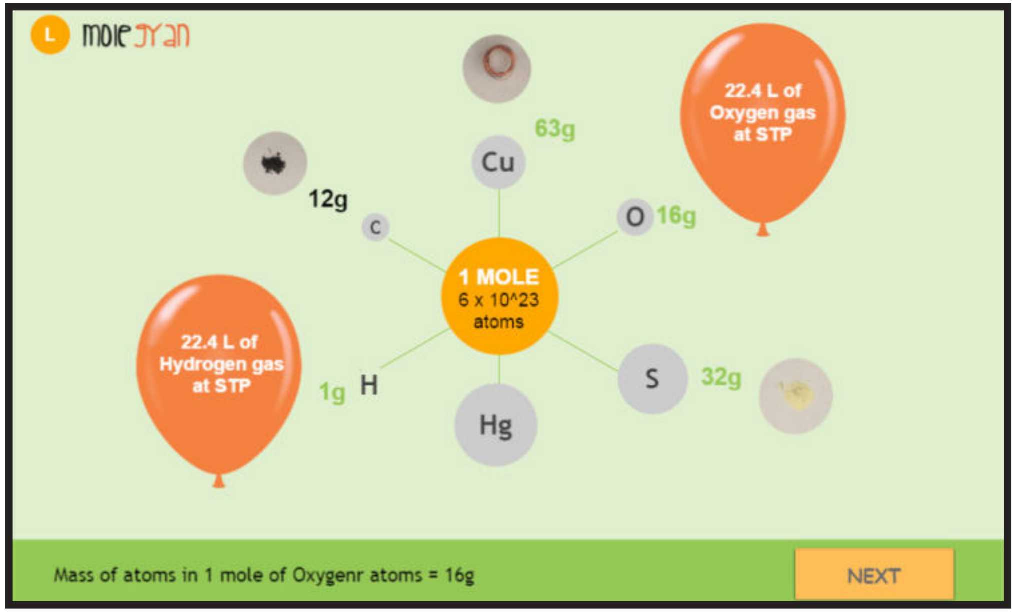


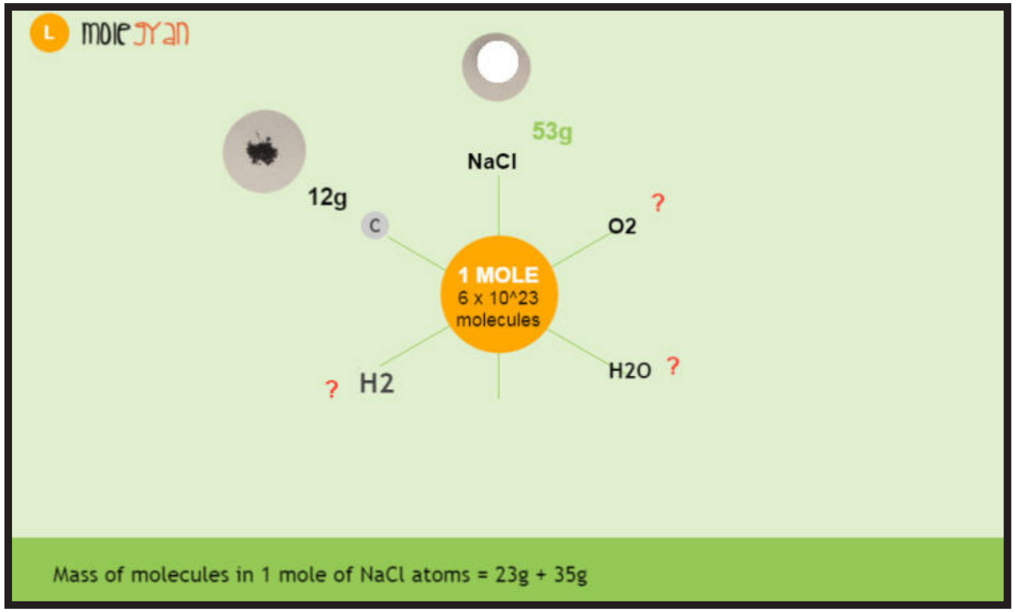


Rohan has to fill the molar mass of each elements. He has to recall the atomic masses from the previous activities.

If the answer is chosen right, a feedback of how much a mole of the element is shown.

Rohan also sees the feedback message 'Mass of atoms in 1 mole of hydrogen atoms = 1g'.



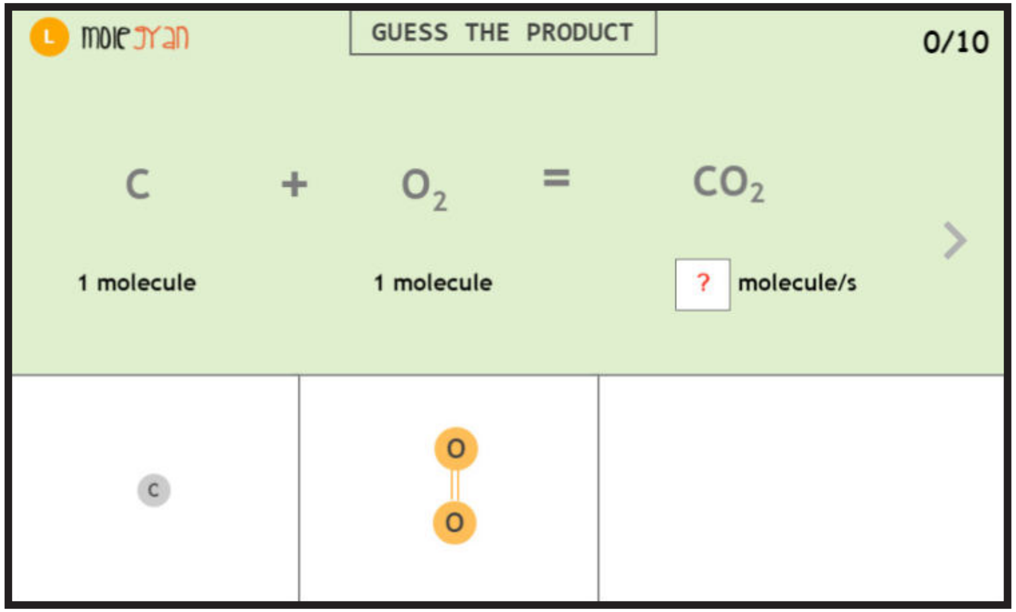


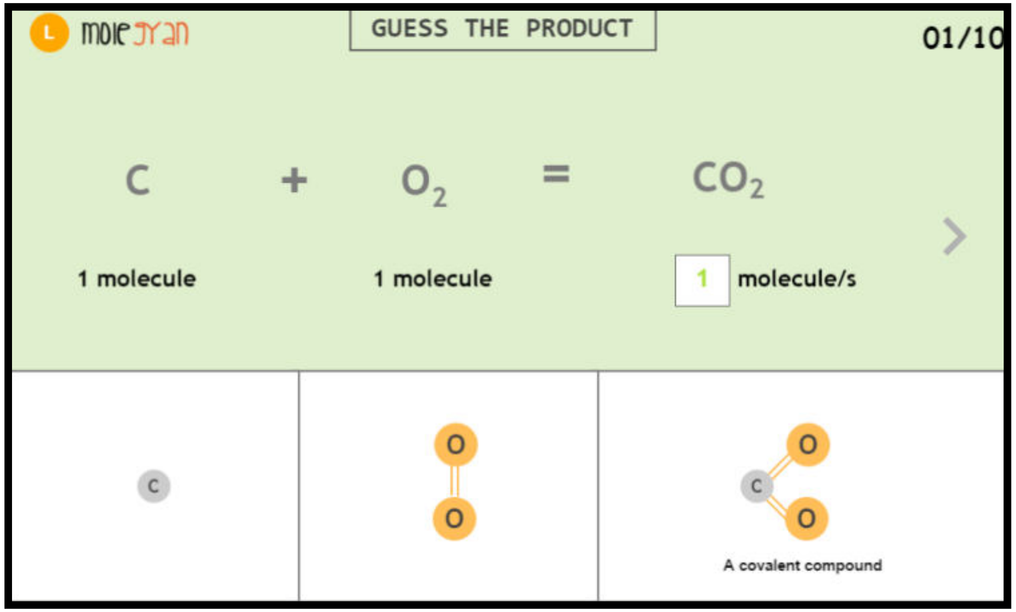
Once Rohan completes filling all the molar masses and reads the feedbacks given, he can proceed to the next activity which is similar , but based on mole of molecules.

The fourth activity is regarding mole of molecules and Rohan has to complete it to go to the next level.

Other scenarios : What if the Rohan faces difficulty while doing the problems and decide to quit - Hints

Level 3: Guess the product

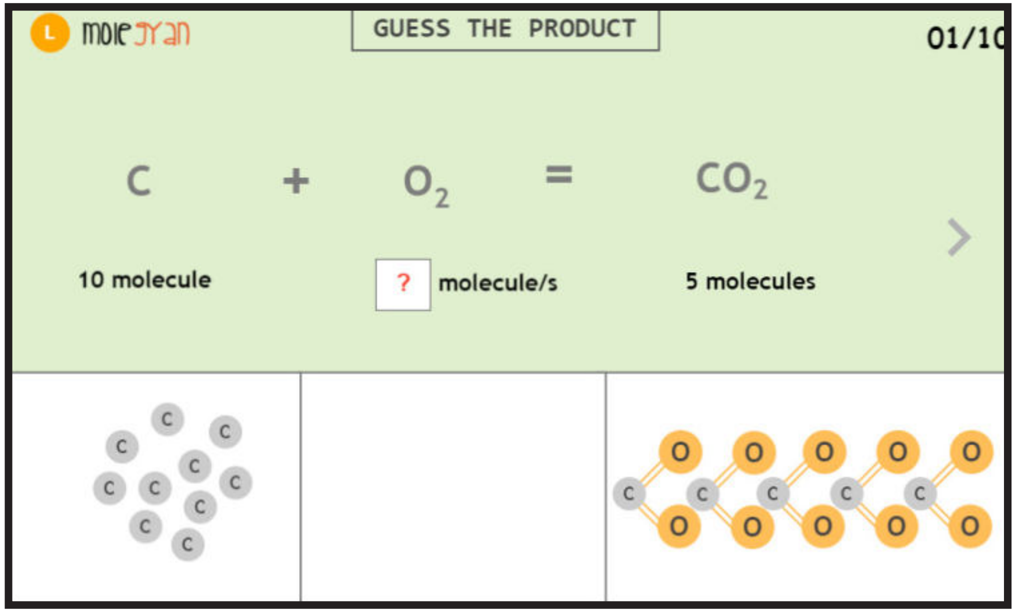


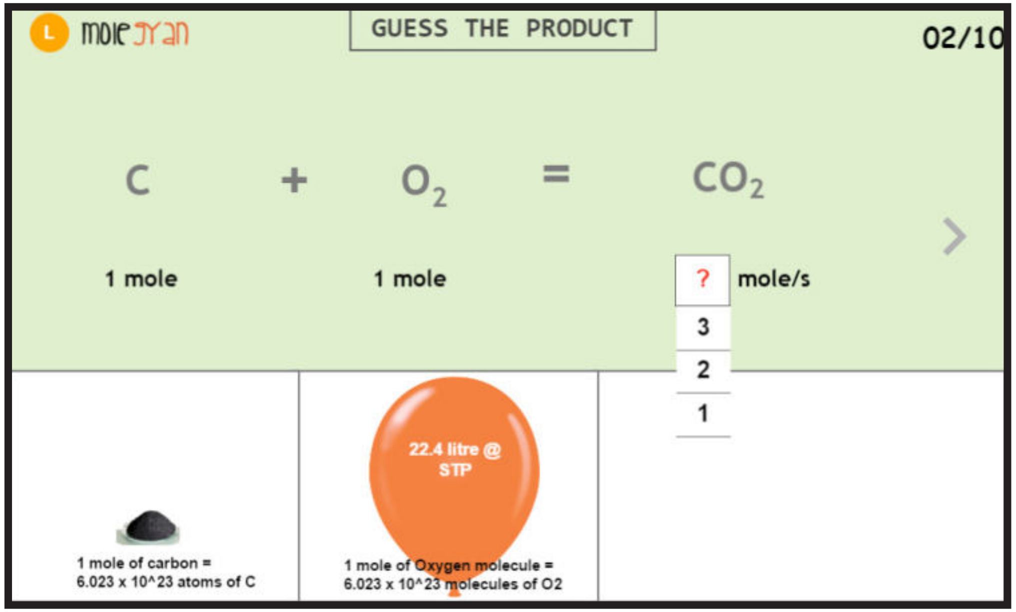


In Level 4, how to answer the first question is demonstrated by a small animation clip. Rohan has to similarly fill the rest of the coefficients of the carbon combustion equation.

The visualization of the respective quantity of reactants and products are shown in boxes below.

If the answer is chosen right, a feedback appears with the product visualization and then Rohan can proceed to the next question.





The Next question is aimed at learning about the effect of limiting reagent on the reaction.

The rest of the questions are on mole which need to be answered in the similar manner.

Level 4: Mole pair game

Evaluation

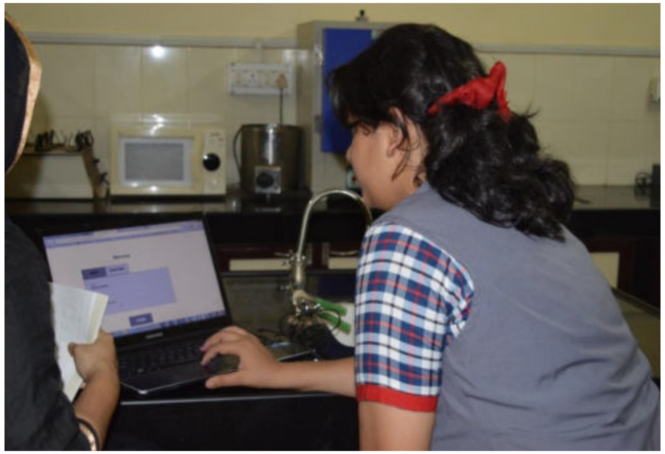


Fig.38: Instance from User Testing

The first three levels of Molegyan application i.e., (Find molecules/Mass, number and mole /Guess the product) were ready for user testing. A day long evaluation plan was made. This time would be spend with students evaluating the learning, engagement and usability goals of the tool. Level 4 – Mole pair game will be tested as paper prototype to validate their understanding on mole. I also thought it would be good to show the tool to few teachers in order to get their input on the content and flow in the tool.

User

The evaluation is conducted with school children from 10th standard from KV School and GHSS Koduvally who are yet to learn mole in detail, but knows the prerequisites. A total of 5 students were evaluated in this stage of prototype with 2-average, 2-good and 1- excellent academic performance according to teacher. This could lead to holistic findings and not a biased view if only excellent students are taken.

Key Questions

The scope of evaluation was on learning, engagement and usability of the tool.

1. Is the learning effective ?

The learning goals of the UT for each of the 3 levels are derived from the objectives and are as follows. The products effectiveness can be analysed by measuring their progress in achieving the following goals.

Level 1 : Find molecules ;

Students must be able to identify that elements are of different type - mono atomic, diatomic and poly-atomic and molecules can be ionic and covalent.

Students must be able to deduce that atoms are not all the same (misconception) and atoms of different elements are of different masses.

Level 2 : Mass, number and Mole

Students must be able to compare and calculate molecular mass of elements from atomic masses , relative atomic masses and molar masses

Students must be able to differentiate between mole of atoms and mole of molecules

Level 3 : Guess the product

Students must understand the usage of mole in stoichiometry

Students must be able to predict the quantity(number of molecules, moles, mass, volume) of reactants or products from those given in the equation.

2. Should the difficulty level of the activities increase, decrease or remain the same ?

3. Is the product engaging ?

For the first 3 levels, the user must be motivated enough to find all the right answers from the feedback given and not quit in between. The user must read the feedback messages and visuals given in each stage. The user must listen attentively to at least one of the videos.

For level 4 - test stage, user must be able to find at least 4 mole pairs from the game without loosing interest or engagement.

4. Are there any usability issues with the product ?

Method

The method of the evaluation protocol with each student comprised of a 3 minute introduction to mole, Exploration of the product levels 1-3, Playing the level 4-mole pair game and Post test questions. The exploration task is monitored in person and as video, without being much of an intrusion to the user. In case of doubts or being stuck at a stage due to limitations of prototype, help was immediately given.

An HTML version of the prototype was extracted and evaluation was done partially in a windows laptop and linux desktop. The students recruited were tested beforehand for their proficiency in computer usage and were found to be well versed in using basic softwares and internet. Hence, no training or instruction was provided in regard to usage.

The 3 minute introduction to mole comprised of either listening to the audio clip of the script given in the content analysis or teaching by the evaluator wherever it is not available. This is done as most students would have forgotten the content or teachings due to the time gap.The self explore session begins from the start screen of molegyan and student will linearly go through levels. Level 4 game was drawn on paper and asked to identify the pairs. This level is used as a test for determining the students understanding on mole.

Post test questions

1. Classify into monoatomic, diatomic and poly-atomic elements. Compare their atomic model

-Sulphur, Phosphorous, Carbon and Nitrogen

2. If atomic mass of Sulphur is 32 and then what is its molecular mass . Compare it with carbon

3. What is the relative atomic mass of Sulphur.

4. If I have 1 mole of sulphur atoms, How many atoms do i have ?

5. If I weigh 1 mole of sulphur atoms, What will I get on the weighing meter? Will it be less than or more than a mole of oxygen atoms?

Fig.39: Post test questioning during user testing

Findings

Difficulty level

Measure of difficulty level was done through the number of wrong moves done by the students during the activity. The Levels 2 and 3 were of adequate difficulty level. But level 4 was too difficult to proceed for students. Level 1 was too easy for 3 students.

Engagement

All the activities were engaging to the students where as the videos created boredom after a point they quit watching them. Some instances in the activities were disengagment were observed are while reading the feedback notes in the level 1 and level 3. These feedbacks were viewed with indifference by half of the users.

Usability

There were difficulty in understanding the usage instructions in Activity about mole in level 2 (page no.77) and the initial question of level 3 (page no.80). The evaluator had to explain the activity to the user as they were stuck. The solution is to provide answer for one question showing the way to do it.

There were usability issues in Activity about mole in level 2 (page no.77) due to forgetting the atomic mass of elements and as they were not provided. Students wanted to go back to the previous levels to check the answers given, which was not possible in the prototype.

Learning Method

The activity level based approach of Molegyan was a variety scenario to the students who didnot have such activity for mole and it was not monotonous like rote learning. It also gave them a break from the classroom scenario reducing disengagement in class. With inclusion of more number of elements, molecules and compounds in levels , Molegyan has the capability of becoming a standalone tool for motivated students.

Learning

Mine or teachers presence tend to be have a slight effect on expressing or exploring the learning. In level one it was observed that once the students understood that there is hint provided for all atoms, they would first look at the hint and then perform the action of combining molecules. This reduced the learning and hence, hints should be restricted to first 2 or 3 examples. In levels 2 and 3 students tend to make small math calculation mistakes, which doenot effect the score right now. This gives undue advantage for students and the mistakes should reflect in the scoring.

Notes and feedbacks given lower importance compared to actions.

One major finding from level 3 is that students tend to conserve number of molecules. This shows a basic lack of understanding about reactions and hence a study video should be provided her.

Specific learning in each level is not evident enough to certain children as their main aim is to finish the game/activity. Hence the take away from each level should be shown upfront as a summary.

Students lacked knowledge about molar volume and the value 22.4l.

From the post test questions, it was understood that students have understood the basic concepts when asked in the flow , but find difficulty in comparing with other elements. Practising the activity multiple times might help them able to compare quantities of elements too,

Teacher feedback

Level 1 (Find molecules)

Good initial activity to build interest in the entire process. Rather than focusing on smallness of atoms in the initial note, It is better to explain what is mono, dia and poly atomic elements. Size of the visualization of atoms(Fig.39) might create misconceptions in future chemistry classes.

Level 2 (Mass and Mole)

Is introducing relative mass a right action as it was makes students usually confused during the class sessions.

And if as relative atomic mass is introduced, relative molecular mass and molecules of compounds can be also introduced in level 2 to avoid misconception.

Level 4

Mole pair game is currently too difficult to solve due to mixing mole of atoms, molecules, ions,mass and number. and hence it cannot be used as a testing tool for mole. This tile formation (Fig. 40) can come as a 4th level of the game after concentrating on one aspect in each level initially. It should be made engaging .

Usage : Teachers were very weak in using the product and understanding the flow compared to students.

According to the teachers, For students with very low knowledge on basics , there will still be difficulty in understanding flow. Only 20% students in her class can do it without learning mole, but the rest 80% - as activity after teaching mole.

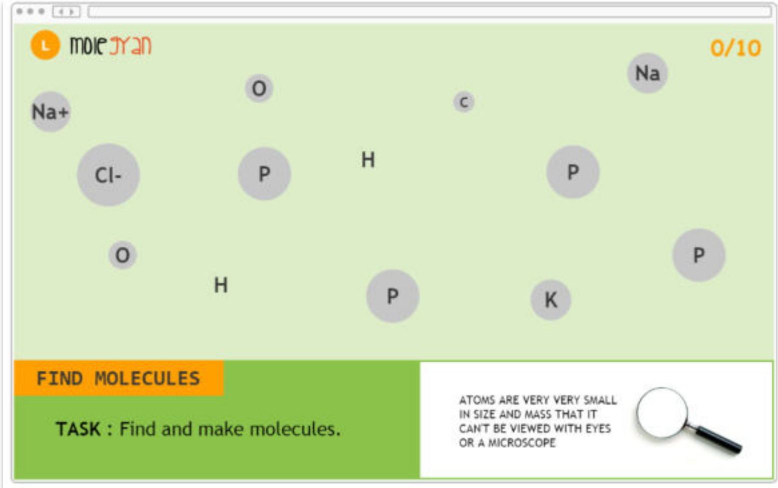


Fig.39: Size of atoms based on mass might create future misconceptions

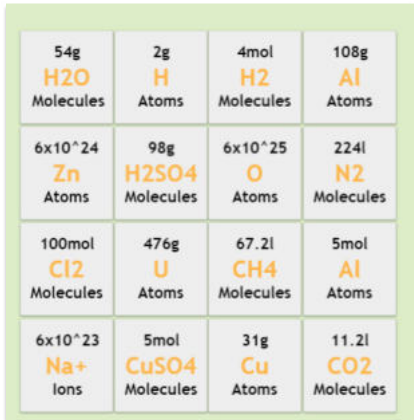


Fig.40: Mole pair game too difficult

Design changes

Mole video should be shown as a compulsory video for better understanding and performance. A significance improvement was seen in molepair game, in students who attentively listened to the video

As students forgot certain learnings from the previous levels and wanted to retrieve it for doing the new activity, there should be a method to view learnings/summary from previous activities(especially,level 1 and 2) easily without actually doing those levels all over again.

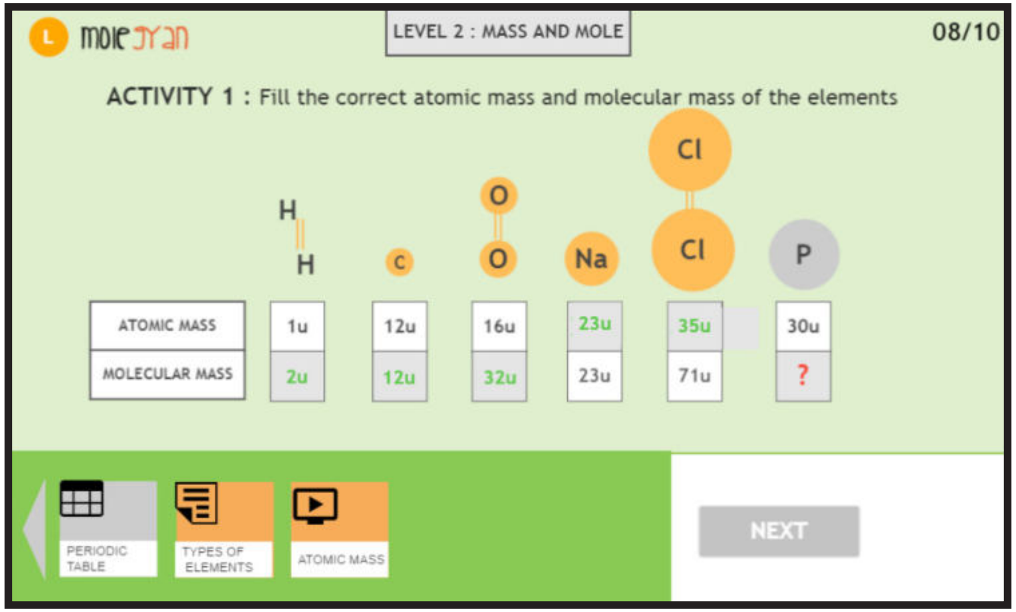
Regarding usability, steps should be taken to make instructions and feedback more evident and in the forefront.

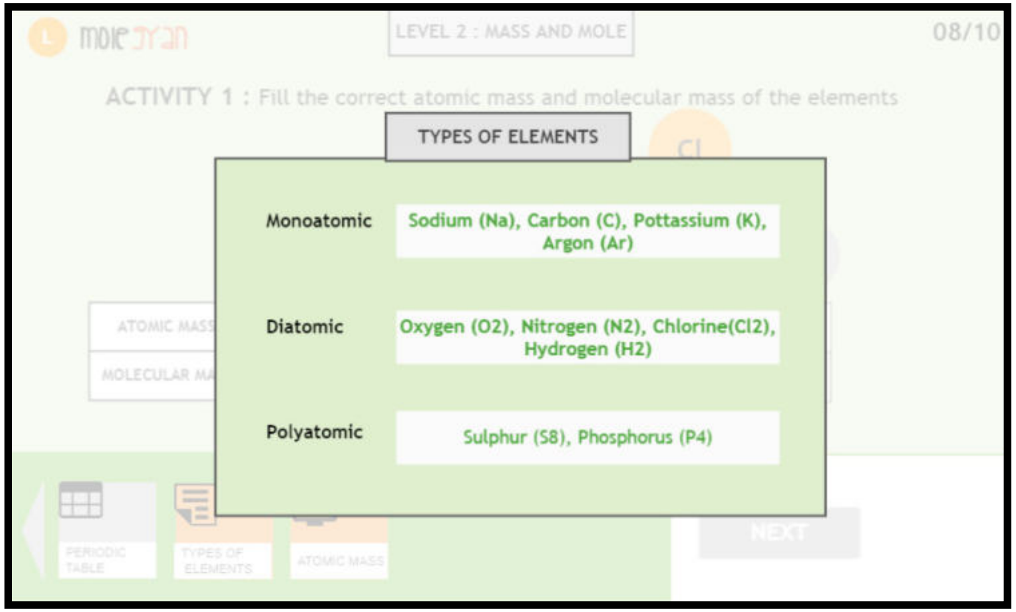
The difficulty of the mole pair game should be substantially reduced and maybe difficulty based levels can be introduced here.

An advanced level of molegyan can be the future scope incorporating more elements, molecules and stoichiometry in equations.

Changes made

Based on the findings, following changes were made. A note screen was provided at the end of each activity summarising the activity which can be retrieved later from the video reference tab in he bottom It also updates with resourses like periodic table.



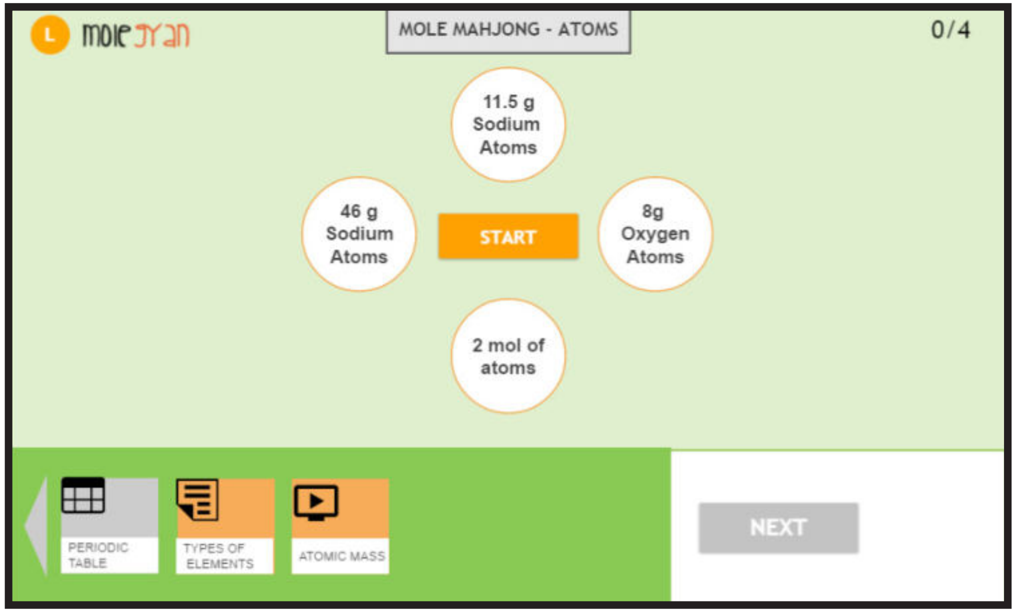


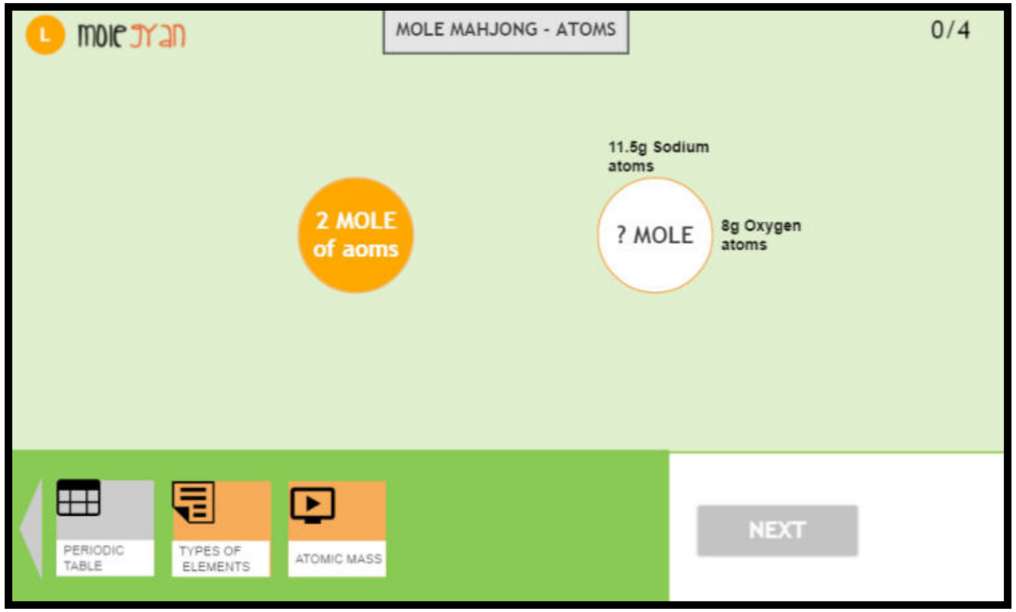
The references bar at the bottom which earlier contained only videos also shows notes and other materials. Those notes or videos that are not viewed are highlighted. The 'types of elements' note was added after the level 1 activity- find molecules.

As Rohan realises that making a wrong selection affects his score, he is keen to select only the right answer. He has doubt in the molecular model of phosphorus. So, he decides to click the note and see.

In the note, he finds Phosphorous to be tetra atomic and hence, he calculates molecular mass 4 times of the atomic mass. Similarly, summary is generated from each level which can be accessed in the subsequent levels.

Based on the findings, following changes were made to the mole pair game. The game was divided into multiple levels, the first level being the basic with 4 tiles of mole of atoms alone. The second level moves on to mole of molecules. The 3rd level is upgraded with 6 tiles. Strict scoring is provided in the level to reduce random moves.





Once mole mahjong game is selected, the first activity appears. This is a very basic conversion game involving only mole of atoms and 2 elements. At the beginning voice instruction will be given as " The task is to find pairs having equal number of atoms. The game can be played by combing the required circles. Please not that wrong moves will cost you valuable points."

Rohan finds the first pair easily as number of moles were given. Once 1 pair is done, in the case of the other pair, number of moles also need to be found out and entered. If rightly entered , the game proceeds to next level.

Conclusion

Product was successful with respect to certain learning outcomes but the design for breaking misconceptions can improve.

A mixture of video learning and activity (tangible or digital) is the best for self learning mole concept.

The product should be in context to students level of knowledge at different classes.

As mole is a nested concept, learning or revising the prerequisites is a must before entering the core subject.

Future scope : Prototype can be developed with more levels and more elements and activities in each level. Both design explorations can be combined, by using mole Scope as an explorer.

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